Prepared for:
**US EPA Region 1**
**Boston, Massachusetts**
Project: EPA-SMP-07-002

# Total Maximum Daily Load for Tom Pond, Warner, NH

DRAFT

Prepared by AECOM, 171 Daniel Webster Hwy, Suite 11, Belmont, NH 03220
July 2009
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# Executive Summary

A Total Maximum Daily Load (TMDL) analysis was conducted for Tom Pond, New Hampshire. Tom Pond is currently listed as impaired for primary contact recreation by the State of New Hampshire because of high chlorophyll *a* concentrations. This effort included the construction of a nutrient budget and setting a target value for phosphorus such that algal growth and bloom formation would no longer impair primary contact recreation. The TMDL is then allocated among sources of phosphorus such that in-lake phosphorus concentrations meet the target and Tom Pond supports its designated uses. The analysis suggests that the current loads of phosphorus to Tom Pond must be reduced by 3% overall in order to meet the target in-lake phosphorus value of 12 μg/L. The load allocation puts primary emphasis on reducing watershed phosphorus sources over other sources due to the relative load contribution from the watershed and practical implementation considerations. It is expected that these reductions would be phased in over a period of several years. Successful implementation of this TMDL will be based on compliance with water quality criteria in Env-Wq 1700. Guidance for obtaining Clean Water Act (Section 319) funding for nonpoint source control is presented in Section 7.0. Suggestions for enhancement of the current monitoring program and general phosphorus loading reduction strategies are also provided.

# 1.0 Introduction

The Federal Clean Water Act (CWA) provides regulations for the protection of streams, lakes, and estuaries within the United States. Section 303(d) of the CWA requires individual states to identify waters not meeting current state water quality standards due to pollutant discharges and to determine Total Maximum Daily Loads (TMDLs) for these waters. A TMDL sets the maximum amount of a pollutant that a waterbody can receive and still support designated uses. A large number of New Hampshire lakes are on the 2006 and 2008 303(d) lists due to impairment of designated uses by chlorophyll *a* (chl *a*), cyanobacteria blooms or dissolved oxygen (DO) depletion (NH DES, 2006a, 2008b). Tom Pond is included on the 2006 and 2008 lists due to the impairment of primary contact recreation caused by high chl *a* concentrations. High levels of chl *a* are indicative of nutrient enrichment. Phosphorus is the primary limiting nutrient in northern temperate lakes, hence eutrophication due to phosphorus enrichment is the likely cause of high chl a, presence of hepatotoxic cyanobacteria, and/or low DO. Nitrogen can also play a role in determining the type of algae present and the degree of eutrophication of a waterbody. However, phosphorus is typically more important and more easily controlled. A TMDL for total phosphorus (TP) as a surrogate for chl *a* has been prepared for Tom Pond and the results are presented in this report.

The TMDL will be expressed as:

TMDL = Waste Load Allocation (WLA) + Load Allocation (LA) + Margin of Safety (MOS)

The WLA includes the load from permitted discharges, the LA includes non-point sources and the MOS ensures that the TMDL will support designated uses given uncertainties in the analysis and variability in water quality data.

Determining the maximum daily nutrient load that a lake can assimilate without exceeding water quality standards is challenging and complex. First, many lakes receive a high proportion of their nutrient loading from non-point sources, which are highly variable and are difficult to quantify. Secondly, lakes demonstrate nutrient loading on a seasonal scale, not a daily basis. Loading during the winter months may have little effect on summer algal densities. Finally, variability in loading may be very high in response to weather patterns, and the forms in which nutrients enter lakes may cause increased variability in response. Therefore, it is usually considered most appropriate to quantify a lake TMDL as an annual load and evaluate the results of that annual load on mid-summer conditions that are most critical to supporting recreational uses. Accordingly, the nutrient loading capacity of lakes is typically determined through water quality modeling, which is usually expressed on an annual basis. Thus, while a single value may be chosen as the TMDL for each nutrient, it represents a range of loads with a probability distribution for associated water quality problems (such as algal blooms). Uncertainty is likely to be very high, and the resulting TMDL should be viewed as a nutrient-loading goal that helps set the direction and magnitude of management, not as a rigid standard that must be achieved to protect against eutrophication. While daily expression of the TMDL is provided in this report, the annual mean load should be given primacy when developing and evaluating the effectiveness of nutrient loading reduction strategies.

The purpose of the Tom Pond TMDL is to establish TP loading targets that, if achieved, will result in consistency with the State of New Hampshire Water Quality criteria Env-Wq 1703.14. Water quality that is consistent with state standards is, *a priori*, expected to protect designated uses. AECOM prepared this TMDL analysis according to the United States Environmental Protection Agency's (US EPA) protocol for developing nutrient TMDLs (US EPA, 1999). The main objectives of this TMDL report include the following:

- Describe water body, standards and numeric target value;
- Describe potential sources and estimate the existing TP loading to the lake;
- Estimate the loading capacity;

- Allocate the load among sources;
- Provide alternate allocation scenarios;
- Suggest elements to be included in an implementation plan;
- Suggest elements to be included in a monitoring plan;
- Provide reasonable assurances that the plans will be acted upon; and
- Describe public participation in the TMDL process.

This TMDL for TP will identify the causes of impairment and the pollutant sources and is expected to fulfill the first of the nine requirements for a watershed management plan required to qualify a project for Section 319 restoration funding (see Section 7.0).

# 2.0 Description of Water Body, Standards and Target

## 2.1 Waterbody and Watershed Characteristics

Tom Pond (NHLAK700030304-05) is located in Warner, New Hampshire and is within the Merrimack River Basin (Figure 2-1). The 13-hectare (ha) lake has a maximum depth of 4.1 meters (m) (13.5 ft) and a mean depth of 2.3 m (7.5 ft). The lake volume is 294,344 cubic meters ($m^3$) with a flushing rate of approximately six times per year. The watershed area is 298 ha and is predominately within the Town of Warner with a small portion of the watershed in the Town of Hopkinton. The Town of Warner has 2,973 residents (ELMIB, 2007). Select characteristics of Tom Pond and its watershed are presented in Table 2-1.

**Table 2-1. Characteristics of Tom Pond, Warner, NH.**

| **Parameter** | **Value** |
|---|---|
| Assessment Unit Identification | NHLAK700030304-05 |
| Lake Area (ha) | 13 |
| Lake Volume ($m^3$) | 294,344 |
| Watershed Area (ha) | 298 |
| Watershed/Lake Area | 23 |
| Mean Depth (m, ft) | 2.3, 7.5 |
| Max Depth (m, ft) | 4.1, 13.5 |
| Flushing Rate ($yr^{-1}$) | 6.4 |
| Epilimnetic TP (*u*g/L mean, range)* | 10, 5-23 |
| Hypolimnetic TP (*u*g/L mean, range)* | 12, 6-20 |
| Epilimnion TN: TP Ratio | 38 |
| Impaired Uses and Causes of Impairment** | *Primary Contact Recreation*: Chlorophyll *a;* Source Unknown |
| Hypolimnetic Anoxia | Yes, Weakly Stratified |

*Water quality statistics are calculated from 2001-2007 data.
**Source: 2006 & 2008 NH 303d Lists of Threatened or Impaired Waters that Require a TMDL. Category '5'= TMDL Required, Category 'M'= Marginal Impairment, and Category 'P'= Priority Impairment.

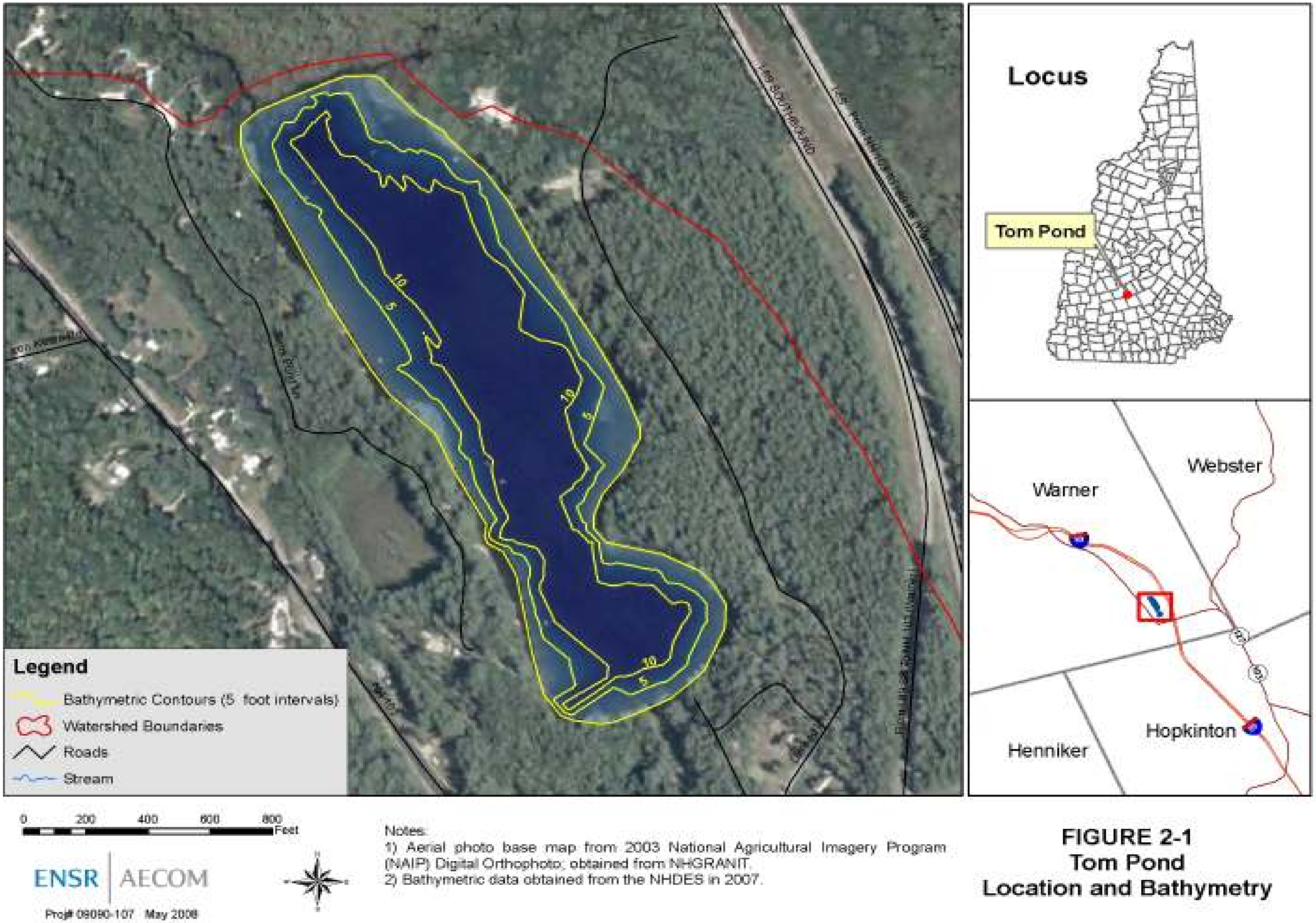



**Figure 2-1. Tom Pond Location and Bathymetry.**

The New Hampshire Department of Environmental Services (NH DES) conducted water quality monitoring of Tom Pond in 1980, 1998, and 2006 for Lake Trophic Studies (NH DES, 1998). The Volunteer Lake Assessment Program (VLAP) began in 1987 and continues to the present day (NH DES, 2006b). The mean, median and range of selected summer water quality parameters from each sampling location from the most recent data available (2001-2007) are summarized in Table 2-2. The lake is weakly stratified, but the hypolimnion still can have low DO concentrations (< 1 mg/L) at depths below 4.0 m during the summer. Secchi disk transparencies (SDT) range from 1.8 to 3.8 m with a mean of 2.9 m. Chl *a* concentrations over this time period range from 4.6 to 36.7 μg/L. TP concentrations in the epilimnion range from 5 to 23 μg/L with a mean of 10 μg/L. Hypolimnetic TP concentrations range from 6 to 20 μg/L with a mean of 12 μg/L. The mean epilimnetic and hypolimnetic TP concentrations are similar and the lake is only weakly stratified; therefore sediment release of TP is not expected to be a major source to Tom Pond.

**Table 2-2. Lake Summer Water Quality Summary Table 2001-2007.**

| Statistic | Epi TP (ug/L) | Hypo TP (ug/L) | Inlet TP (ug/L) | Outlet TP (ug/L) | SDT (m) | Chl a* (ug/L) | DO ** (mg/L) |
|---|---|---|---|---|---|---|---|
| **n** | 22 | 22 | 16 | 21 | 21 | 22 | 39 |
| **Min** | 5 | 6 | 13 | 6 | 1.8 | 4.6 | 0.1 |
| **Mean** | 10 | 12 | 54 | 13 | 2.9 | 9.5 | 2.0 |
| **Max** | 23 | 20 | 184 | 31 | 3.8 | 36.7 | 4.0 |
| **Median** | 10 | 12 | 53 | 12 | 3.0 | 7.9 | 2.0 |

n = number of samples; Epi = epilimnion; Hypo = hypolimnion; SDT= Secchi Disk Transparency, Chl *a*= Chlorophyll *a*, DO= Dissolved Oxygen
* Uncorrected for phaeophytin
** DO values are from each discrete observation in the data set regardless of depth

## 2.2 Designated Uses

Tom Pond is assigned a surface water classification of B by the State of New Hampshire. Surface water classifications establish designated uses for a waterbody. Designated uses are desirable uses that must be protected, but are not specifically associated with quantifiable water quality standards. According to RSA 485-A:8, Class B waters, "…shall be of the second highest quality." These waters are considered acceptable for fishing, swimming and other recreational purposes and may be used as water supplies after adequate treatment.

As indicated above, State statute (RSA 485-A:8) is somewhat general with regards to designated uses for New Hampshire surface waters. Upon further review and interpretation of the regulations (Env-Wq 1700), the general uses can be expanded and refined to include the seven specific designated uses shown in Table 2-3 (NH DES, 2008a).

**Table 2-3. Designated Uses for New Hampshire Surface Waters**

| Designated Use | NH DES Definition | Applicable Surface Waters |
|---|---|---|
| Aquatic Life | Waters that provide suitable chemical and physical conditions for supporting a balanced, integrated and adaptive community of aquatic organisms. | All surface waters |
| Fish Consumption | Waters that support fish free from contamination at levels that pose a human health risk to consumers. | All surface waters |
| Shellfish Consumption | Waters that support a population of shellfish free from toxicants and pathogens that could pose a human health risk to consumers | All tidal surface waters |
| Drinking Water Supply After Adequate Treatment | Waters that with adequate treatment will be suitable for human intake and meet state/federal drinking water regulations. | All surface waters |
| Primary Contact Recreation (i.e. swimming) | Waters suitable for recreational uses that require or are likely to result in full body contact and/or incidental ingestion of water | All surface waters |
| Secondary Contact Recreation | Waters that support recreational uses that involve minor contact with the water. | All surface waters |
| Wildlife | Waters that provide suitable physical and chemical conditions in the water and the riparian corridor to support wildlife as well as aquatic life. | All surface waters |

## 2.3 Applicable Water Quality Standards

The New Hampshire State Water Quality Standards for nutrients in Class B waters (Env-Wq 1703.14) are:

(1) **Class B** waters shall contain no phosphorus in such concentrations that would impair any existing or designated uses, unless naturally occurring.

(2) Existing discharges containing either phosphorus or nitrogen that encourage cultural eutrophication shall be treated to remove phosphorus or nitrogen to ensure attainment and maintenance of water quality standards.

(3) There shall be no new or increased discharge of phosphorus into lakes or ponds.

(4) There shall be no new or increased discharge(s) containing phosphorus or nitrogen to tributaries of lakes or ponds that would contribute to cultural eutrophication or growth of weeds or algae in such lakes and ponds.

Applicable water quality standards for DO include the following:

Env-Wq 1703.07 (b): Except as naturally occurs, or in waters identified in RSA 485-A:8, **III**, or subject to (c) below, Class B waters shall have a DO content of at least 75% of saturation, based on a daily mean, and an instantaneous minimum DO concentration of at least 5 mg/L.

Env-Wq 1703.07 (d): Unless naturally occurring or subject to (a) above, surface waters within the top 25 percent of depth of thermally unstratified lakes, ponds, impoundments and reservoirs or within the epilimnion shall contain a DO content of at least 75 percent saturation, based on a daily mean and an instantaneous minimum DO content of at least 5 mg/L. Unless naturally occurring, the DO content below those depths shall be consistent with that necessary to maintain and protect existing and designated uses.

The NH DES policy for interim nutrient threshold for primary contact recreation (i.e. swimming) in NH lakes is 15 μg/L chl *a* (NH DES, 2008a). Lakes were also listed as impaired for swimming if surface blooms (or "scums") of cyanobacteria were present. A lake was listed even if scums were present only along a downwind shore.

## 2.4 Anti-degradation Policy

Anti-degradation provisions are designed to preserve and protect the existing beneficial uses of New Hampshire's surface waters and to limit the degradation allowed in receiving waters. Anti-degradation regulations are included in Part Env-Wq 1708 of the New Hampshire Surface Water Quality Regulations. According to Env-Wq 1708.02, anti-degradation applies to the following:

- All new or increased activity including point and nonpoint source discharges of pollutants that would lower water quality or affect the existing or designated uses;
- A proposed increase in loading to a waterbody when the proposal is associated with existing activities;
- An increase in flow alteration over an existing alteration; and
- All hydrologic modifications, such as dam construction and water withdrawals.

## 2.5 Priority Ranking and Pollutant of Concern

Tom Pond (NHLAK700030304-05) is listed on the 2006 and 2008 303(d) list as having primary contact recreation use impairment due to excessive chl *a* (NH DES, 2006a, 2008b). Tom Pond periodically experiences high concentrations of chl *a* in summer. Tom Pond is listed by the NH DES as a low priority for TMDL development. This preliminary ranking is based on the waterbody impairment and whether the pollutants pose a threat to human health or to federally listed, threatened or endangered species (NH DES, 2008a). The final ranking takes into account public interest/support, availability of resources for development, administrative or legal factors, and likelihood of implementation. When the 2006 and 2008 303(d) lists were prepared, it was unknown if funding would be available for development of this TMDL; consequently it was given a low ranking at the time. Designated use impairment is also ranked. Tom Pond is listed as marginally impaired (category 5-M) for primary contact recreation due to chl *a* levels. It is likely that the impairments observed in Tom Pond are attributable to nutrient enrichment, specifically TP. Control of TP sources to Tom Pond should therefore improve conditions related to chl *a* such that designated uses are supported. A summary of the impairments and causes of impairment are presented in Table 2-1.

## 2.6 Numeric Water Quality Target

To develop a TMDL for this waterbody, it is necessary to derive a numeric TP target values (e.g., in-lake concentration) for determining acceptable nutrient loads. The suggested TP values are described in the following paragraphs. The derivation of these targets and discussion of alternative approaches in setting targets are presented in Appendix A. It is notable that all three approaches presented result in very similar target concentrations.

At present, numeric criteria for TP do not exist in New Hampshire's state water quality regulations. Accordingly, best professional judgment of AECOM, NH DES, and US EPA Region 1 was employed to select a quantitative target in-lake TP concentration that will attain the narrative water quality standard. Wind accumulation of surface blooms or "scum" can be cause for impairment in New Hampshire lakes. It is difficult to relate the presence of these scums to TP loads. However, setting a TP target based in part on minimizing the probability of excessive summer chl *a* should be sufficient to minimize scum formation.

The numeric (in-lake) water quality target for TP for Tom Pond is 12 μg/L, based on the discussion presented in Appendix A. The target is set based on an analysis of the observed TP concentrations from a set of impaired and a set of unimpaired lakes in New Hampshire. The target number is supported by evaluation of the Trophic State Indices (TSI) developed by Carlson (1977) and a probabilistic assessment of the likelihood of blooms (Walker 1984, 2000). The "weight of evidence" suggests that 12 μg/L is an appropriate target that will allow Tom Pond to support its designated uses. This target incorporates an MOS (described further in Section 5.3). The target is based primarily on summer data but the TMDL is being calculated based on mean annual conditions. The target concentration corresponds to non-bloom conditions, as reflected in suitable (designated use support) measures of both SDT and chl *a*.

# 3.0 ENSR-LRM Model of Current Conditions

Current TP loading was assessed using the ENSR-LRM methodology, which is a land use export coefficient model developed by AECOM for use in New England and modified for New Hampshire lakes by incorporating New Hampshire land use TP export coefficients when available and adding septic system loading into the model (CT DEP and ENSR, 2004). Documentation for ENSR-LRM is provided in Appendix B.

The major direct and indirect nonpoint sources of TP to Tom Pond include:

- Atmospheric deposition (direct precipitation to the lake)
- Surface water base flow (dry weather tributary flows, including any groundwater seepage into streams from groundwater)
- Stormwater runoff (runoff draining to tributaries or directly to the lake)
- Waterfowl (direct input from resident and migrating birds)
- Direct groundwater seepage including septic system inputs from shorefront residences
- Periodic Flooding from the Warner River

Since the lake is weakly stratified and the mean summer epilimnion and hypolimnion TP are similar, internal loading was not expected be a major TP source to Tom Pond. Internal loading therefore was not calculated in the current conditions model.

There are no permitted point source discharges of nutrients in this watershed. However, construction activities in the watershed that disturb greater than one acre of land and convey stormwater through pipes, ditches, swales, roads or channels to surface water require a federal General Permit for Stormwater Discharge from Construction Activities. However, construction discharges are not incorporated in the model due to their variability and short-term impacts.

The watershed of Tom Pond contains one small tributary draining the southern wetland complex, but much of the watershed is sandy floodplain of the Warner River. The presence of a gravel pit near the pond also demonstrates that sandy soils exist in the Tom Pond watershed. Due to the predominately sandy, highly permeable soils, the watershed was treated as all Direct Drainage (Figure 3-1). TP loads were estimated based on runoff and groundwater land use export coefficients. The TP loads were then attenuated as necessary to tributary monitoring if available. If no tributary data were available or current, then the attenuation factor was based on the slope, soils, and wetland attenuation. Loads from the watershed as well as direct sources were then used to predict in-lake concentrations of TP, chl *a*, SDT, and algal bloom probability. The estimated load and in-lake predictions were then compared against in-lake concentrations. The attenuation factors were used as calibration tools to achieve a close agreement between predicted in-lake TP and observed mean/median TP. However, perfect agreement between modeled concentrations and monitoring data were not expected as monitoring data are limited for some locations and are biased towards summer conditions when TP concentrations are expected to be lower than the annual mean predicted by the loading model.

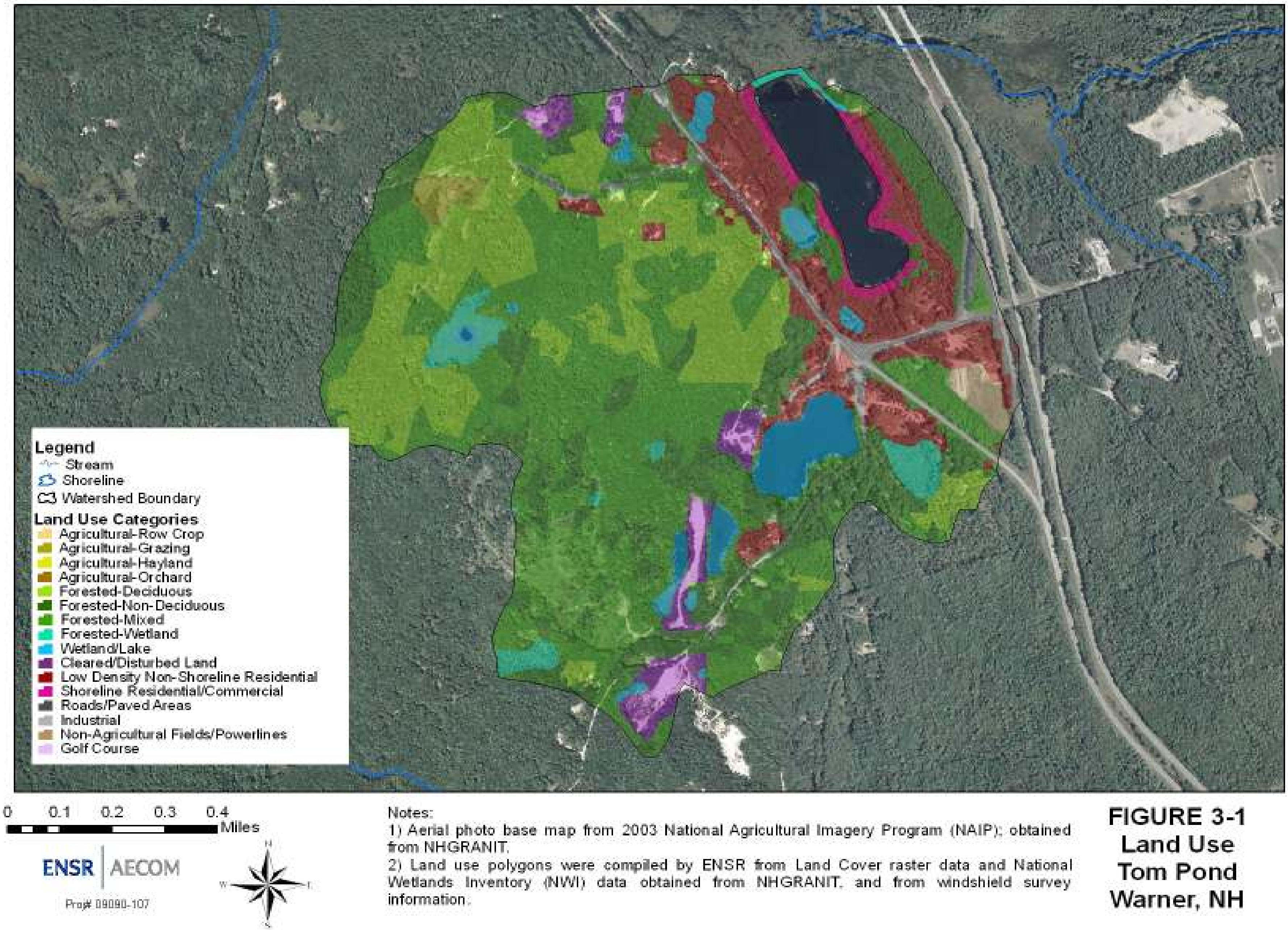



**Figure 3-1. Tom Pond Watershed Land Use.**

## 3.1 Hydrologic Inputs and Water Loading

Calculating TP loads to Tom Pond requires estimation of the sources of water to the lake. The three primary sources of water are: 1) atmospheric direct precipitation; 2) runoff, which includes all overland flow to the tributaries and direct drainage to the lake; and 3) baseflow, which includes all precipitation that infiltrates and is then subsequently released to surface water in the tributaries or directly to the lake (i.e., groundwater). Baseflow is roughly analogous to dry weather flows in streams and direct groundwater discharge to the lake. The water budget is broken down into its components in Table 3-1. Tom Pond also receives hydrologic input from the periodic backflow of the Warner River during times of high river flow. This is discussed in the next section.

- Precipitation - Mean annual precipitation was assumed to be representative of a typical hydrologic period for the watershed. The annual precipitation value was derived from the USGS publication: Open File Report 96-395, “Mean Annual Precipitation and Evaporation - Plate 2”, 1996 and confirmed with precipitation data from weather stations in Epping, Durham, and Concord. For the Tom Pond watershed, 1.03 m of annual precipitation was used.
- Runoff - For each landuse category, annual runoff was calculated by multiplying mean annual precipitation by basin area and a land use specific runoff fraction. The runoff fraction represents the portion of rainfall converted to overland flow.
- Baseflow - The baseflow calculation was calculated in a manner similar to runoff. However, a baseflow fraction was used in place of a runoff fraction for each land use. The baseflow fraction represents the portion of rainfall converted to baseflow.

Runoff and baseflow fractions from Dunn and Leopold (1978) were altered slightly to be representative for sandy soils (i.e. greater infiltration to baseflow). The fractions are the same as those used in the Greenwood Pond TMDL and are listed in Tables C-1 and C-2 in Appendix C (AECOM, 2009b). The hydrologic budget was calibrated to a representative standard water yield for New England (Sopper and Lull, 1970; Higgins and Colonell 1971, verified by assessment of yield from various New England USGS flow gauging stations). The water load was attenuated (reduced) 10% in order to account for the presence of sandy soils, flat terrain near the pond, and small wetlands relatively close to the Tom Pond shoreline. The attenuation was also verified based on best professional judgment and guidance from the Center for Watershed Protection (2000). More detail on the methodology for hydrologic budget estimation and calibration is presented in Appendix B.

**Table 3-1. Tom Pond Water Budget.**

| WATER BUDGET | $M^3$/YR |
|---|---|
| Atmospheric | 134,106 |
| Watershed Runoff | 818,038 |
| Watershed Baseflow | 1,036,884 |
| Total | 1,989,028 |

## 3.2 Nutrient Inputs

***Land Use Export***

The Tom Pond watershed boundary was delineated using NH DES delineations and corrected with USGS topographic maps when necessary (NH DES, 2007). Land uses within the watershed were determined using several sources of information including: (1) Geographic Information System (GIS) data, (2) analysis of aerial photographs and (3) ground truthing (when appropriate).

The TP load for the watershed was calculated using export coefficients for each land use type. The watershed loading was adjusted based upon proximity to the lake, soil type, presence of wetlands, and attenuation provided by Best Management Practices (BMPs) for water or nutrient export mitigation. The watershed load (baseflow and runoff) was combined with direct loads (atmospheric, septic system, and waterfowl) to calculate TP loading. The generated load to the lake was then input into a series of empirical models that provided predictions of in-lake TP concentrations, chl *a* concentrations, algal bloom frequency and water clarity. Details on model input parameters and major assumptions used to estimate the baseline loading (i.e., existing conditions) for Tom Pond are described below.

- Areal land use estimates were generated from land use and land cover GIS data layers from NH GRANIT. For Tom Pond, data sources are: 2001 NH Land Cover Assessment layer © Complex Systems Research Center, University of New Hampshire, and National Wetland Inventory (1971-1992). A Land Use data layer was not available for Warner, NH. Land use categories were matched with the ENSR-LRM land use categories and their respective TP export coefficients. Table C-3 lists ENSR-LRM land use categories in which the GRANIT categories were matched. Land cover data and aerial photographs were used to determine certain land use classifications, such as agriculture and forest types. Selected land uses were confirmed on the ground during a watershed survey. Watershed land use is presented spatially in Figure 3-1 and summarized in Table 3-2.
- TP export coefficient ranges were derived from values summarized by Reckhow et al. (1980), Dudley et al. (1997) as cited in ME DEP (2003) and Schloss and Connor (2000). Table C-3 provides ranges for export coefficients and Table C-4 provides the runoff and baseflow export coefficient for each land use category in Tom Pond and the sources for each export coefficient. Residential areas within the 125ft buffer around the pond were designated as Urban 2 (Shoreline Residential) and residential areas outside of the 125ft buffer were designated as Urban 1 (Low Density Non-shoreline Residential). The export coefficient for Urban 1 was decreased to 0.35 kg/ha/yr as it was assumed that non-shoreline residential would contribute less to the watershed TP load due to it being low density and farther away from the pond. The default export coefficient for Urban 1, 0.9 kg/ha/yr, was instead used for Urban 2 (Shoreline Residential). A University of New Hampshire study also found a TP runoff export coefficient of 0.35 kg/ha/yr to be at the lower end of the range and 0.9 kg/ha/yr to be a moderate export coefficient for urban land use in the Flints Pond watershed (Schloss and Connor, 2000). The land use distribution in the Flints Pond watershed of denser residential along the shoreline and low density non-shoreline residential found is also found in the Tom Pond watershed (AECOM, 2009a).

- Areal loading estimates were attenuated within the model based on natural features such as porous soils, wetlands or by anthropogenic sources, such as implemented physical BMPs that would decrease loading. The Tom Pond watershed has relatively sandy, highly permeable soils. These soils will encourage water infiltration and adsorption of TP to soil particles. Tom Pond also has wetland complexes close to the shoreline. These wetlands are expected to spread the flow and encourage water infiltration, settling and adsorption of TP. Pleasant Pond, which is southwest of Tom Pond, has no surface outlet and likely retains a large amount of the TP originating upgradient of it. A TP attenuation factor of 65% was applied to the Tom Pond Direct Drainage, meaning that 35% of the generated TP load is actually delivered to the lake.
- Annual areal loading of TP from the watershed is estimated to be 24.8 kg/yr, which represents 72% of the total load to the lake.

**Table 3-2. Land Use Categories by Tom Pond Watershed.**

| | Direct Drainage Area (Hectares) |
|---|---|
| Urban 1 (Low Density Non-Shoreline Residential) | 35.3 |
| Urban 2 (Shoreline Residential/Commercial) | 5.2 |
| Urban 3 (Roads) | 9.9 |
| Urban 4 (Industrial) | 0.0 |
| Urban 5 (Parks, Recreation Fields, Institutional) | 2.3 |
| Agric 1 (Cover Crop) | 0.0 |
| Agric 2 (Row Crop) | 0.0 |
| Agric 3 (Grazing) | 2.5 |
| Agric 4 (Hayland-Non Manure) | 0.0 |
| Forest 1 (Deciduous) | 57.1 |
| Forest 2 (Non-Deciduous) | 56.1 |
| Forest 3 (Mixed Forest) | 97.3 |
| Forest 4 (Wetland) | 7.8 |
| Open 1 (Wetland / Pond) | 13.2 |
| Open 2 (Meadow) | 0.0 |
| Open 3 (Bare/Open) | 11.4 |
| TOTAL | 298.2 |

### *Atmospheric Deposition*

Nutrient inputs from atmospheric deposition were estimated based on a TP coefficient for direct precipitation. The atmospheric load of 0.25 kg/ha/yr includes both the mass of TP in rainfall and the mass in dryfall (Wetzel, 2001). The sum of these masses is carried by rainfall. As a result, the concentration calculated for use in the loading estimate 24 μg/L is higher than the mean concentration (25 μg/L) observed in rainfall in Concord, NH (NH DES, 2008 Unpublished Data). The coefficient was then multiplied by the lake area (ha) in order to obtain an annual atmospheric deposition TP load. The contribution of atmospheric deposition to the annual TP load to Tom Pond was estimated to be 3.3 kg/yr or 9% of the total load.

### *Septic systems*

TP export loading from residential septic systems was estimated within the 125 ft shoreline zone. The 125 ft zone is the minimum distance from lakes that new septic systems are allowed in New Hampshire with rapid groundwater movement through gravel soils. A shoreline survey using GIS ortho-photographs determined the number of residencies within the 125 ft zone. It was assumed that if the dwelling was within the 125 ft zone that the septic system was also within the 125 ft zone. The TP load was calculated by multiplying a TP export coefficient (based on literature values for wastewater TP concentrations and expected water use), the number of dwellings, the mean number of people per dwelling, the number of days occupied per year, and an attenuation coefficient (Table C-6). In Tom Pond, the TP loading from shoreline septic systems was estimated to be 5.6 kg/yr, which is 16% of the TP load to Tom Pond. A more detailed septic survey or groundwater monitoring as suggested in Section 8.0 may yield more precise estimates of septic loading.

The following assumptions were used in estimating the TP load from septic systems.

- It was estimated that 18 residences are seasonal and 27 residences are year round (Hamilton, 2008).

- Two and a half people were estimated to reside in each dwelling. It was estimated that each resident uses 65 gallons per day for 365 days per year for year round residents and 90 days for seasonal residents.
- The TP coefficients were calculated based on mean TP concentration in domestic wastewater of 8 mg/L and mean household water uses (Metcalf & Eddy, 1991).
- All septic loads to Tom Pond were attenuated 90% (Dudley and Stephenson, 1973; Brown and Associates, 1980) to account for TP uptake in the soil between the septic systems and the lake. There is no evidence in available watershed reports or evidence from site visits that the majority of the soils underlying the developed area immediately adjacent to Tom Pond has severe limitations for septic systems or has poor filtration characteristics.

***Waterfowl***

Total phosphorus load from waterfowl was estimated using a TP export coefficient and an estimate of annual mean waterfowl population. It was estimated that two Canada Geese reside on the pond (John Hamilton, 2008). The TP export coefficient for Canada Geese, 0.001526 kg/bird/day, was multiplied by 275 non-ice days and the number of waterfowl in order to obtain a TP load of 0.8 kg/yr (Table C-7). This equates to 2% of the total TP load.

***Periodic Backflow of Warner River***

Tom Pond is on the Warner River floodplain and the outlet of Tom Pond is connected via a wetland complex to the river. Since the Tom Pond outlet is only a few feet in elevation above the Warner River, the Warner River periodically floods and backflows into Tom Pond (Hamilton, 2008). Comparing Warner River peak flow data with Tom Pond chl *a* concentrations indicate that high mean summer epilimnion chl *a* concentrations in 2005 and 2006 corresponds with record peak flows (Table 3-3). However, this relationship is imperfect as record peak flows in 2007 correspond with a low mean summer epilimnion chl *a* concentrations. This may be due to the fact that sampling occurs in summer (June-August) while the high flows/flooding occurs in April and May of each year. Also, the pond has an abnormal relationship between TP and chl *a*. As explained in Section 3.5, the observed chl *a* concentrations tend to be higher than what is predicted from empirical equations based on in-lake TP concentrations. Warner River spring flooding may be introducing extra TP into the system that is retained by the outlet wetlands or by the bottom sediments. Heterotrophic phytoplankton, such as the golden-brown *Dinobryon spp*., found in Tom Pond (NH DES, 2006b), may feed off this retained TP and organic matter to cause the abnormally high chl *a* concentrations observed in summer (Smith, 1950). However, this phenomenon is only one possible explanation of the abnormal relationship between TP and chl *a* concentrations observed in Tom Pond. It is recommended that an early spring and summer study be conducted to determine the relationship between Warner River flooding and Tom Pond in-lake chl *a* and TP.

The Warner River backflow to Tom Pond is a potential but currently unquantifiable source of TP to the pond and is not included in the TP budget.

**Table 3-3. Comparison of Tom Pond Chlorophyll a and Total Phosphorus with Warner River Peak Annual Discharge.**

| Year | Tom Pond Mean Epilimnion Chl a (*ug*/L) | Tom Pond Mean TP (*ug*/L) | Peak Discharge* (cfs) | Date of Peak Discharge* |
|---|---|---|---|---|
| 2001 | 7.4 | 8.0 | 2450 | 24-Apr |
| 2002 | 6.6 | 10.7 | 1440 | 14-May |
| 2003 | 9.0 | 8.0 | 1940 | 30-Mar |
| 2004 | 7.1 | 7.3 | 2980 | 2-Apr |
| 2005 | 10.7 | 11.0 | 3640 | 3-Apr |
| 2006 | 17.0 | 14.5 | 8640 | 15-May |
| 2007 | 5.9 | 11.3 | 7730 | 16-Apr |

*Discharge data from USGS Station #01086000, Warner River at Davisville. This station is downstream of Tom Pond.

## 3.3 Phosphorus Loading Assessment Summary

The current TP load to Tom Pond was estimated to be 34.5 kg/yr from all sources. The TP load according to source is presented in Table 3-4.

Loading from the watershed was overwhelmingly the largest source at 24.8 kg/yr (72% of the TP load. Direct precipitation provides approximately 9% of the annual TP load or 3.3 kg/yr while waterfowl contribute only 0.8 kg/yr or 2% of the annual TP load. Septic systems contribute 5.6 kg/yr or 16% of the annual TP budget.

The contribution of backflow from the Warner River was not included in the model representing current conditions because it is not a regular source and the load is difficult to quantify due to lack of data. Also, the current conditions model was calibrated to observed mean summer epilimnetic TP concentrations rather than to mean chl *a* concentrations. However, section 6.0 presents a scenario with the Warner River as an input.

**Table 3-4. Tom Pond Phosphorus Loading Summary.**

| TP INPUTS | Modeled Current TP Loading (kg/yr) | % of Total Load |
|---|---|---|
| Atmospheric | 3.3 | 9 |
| Waterfowl | 0.8 | 2 |
| Septic System | 5.6 | 16 |
| Watershed Load- Direct Drainage | 24.8 | 72 |
| **Total** | **34.5** | **100** |

## 3.4 Phosphorus Loading Assessment Limitations

While the analysis presented above provides a reasonable accounting of sources of TP loading to Tom Pond, there are several limitations to the analysis:

- Precipitation varies among years and hence hydrologic loading will vary. This may greatly influence TP loads in any given year, given the importance of runoff to loading.

- Spatial analysis has innate limitations related to the resolution and timeliness of the underlying data. In places, local knowledge was used to ensure the land use distribution in the ENSR-LRM model was reasonably accurate, but data layers were not 100% verified on the ground. In addition, land uses were aggregated into classes which were then assigned export coefficients; variability in export within classes was not evaluated or expressed.
- TP export coefficients as well as runoff/baseflow exports were representative but also had limitations as they were not calculated for the study water body, but rather are regional estimates.
- The TP loading estimate from septic systems was limited by the assumptions associated with this calculation described above in the "Septic Systems" subsection.
- Water quality data for Tom Pond are limited, restricting calibration of the model. Also, there are no water quality or flow data to quantify the contribution of Warner River backflow into Tom Pond.

## 3.5 Lake Response to Current Phosphorus Loads

TP load outputs from the ENSR-LRM Methodology were used to predict in-lake TP concentrations using five empirical models. The models include: Kirchner-Dillon (1975), Vollenweider (1975), Reckhow (1977), Larsen-Mercier (1976), and Jones-Bachmann (1976). These empirical models estimate TP from system features, such as depth and detention time of the waterbody. The load generated from the export portion of ENSR-LRM was used in these equations to predict in-lake TP. The mean predicted TP concentration from these models was compared to measured (observed) values. Input factors in the export portion of the model, such as export coefficients and attenuation, were adjusted to yield an acceptable agreement between measured and average predicted TP. Because these empirical models account for a degree of TP loss to the lake sediments, the in-lake concentrations predicted by the empirical models are lower than those predicted by a straight mass-balance (17 μg/L) where the mass of TP entering the lake is equal to the mass exiting the lake without any retention. Also, the empirical models are based on relationships derived from many other lakes. As such, they may not apply accurately to any one lake, but provide an approximation of predicted in-lake TP concentrations and a reasonable estimate of the direction and magnitude of change that might be expected if loading is altered. These empirical modeling results are presented in Table 3-5.

The TP load estimated using ENSR-LRM methodology translates to predicted mean in-lake concentrations ranging from 9 to 16 μg/L. The mean in-lake TP concentration of the five empirical models was 12.4 μg/L. The mean and median epilimnetic TP concentration from observed in-lake data from 2001 to 2007 were both 10 μg/L. The slight disagreement between the model results and the in-lake data may be attributable to the time of year of sampling. Nearly all of the monitoring data are from the summer, a time when epilimnetic concentrations are typically lower than mean annual concentrations. The empirical models all predict mean annual TP concentrations assuming fully mixed conditions. Nurnberg (1996) shows summer epilimnetic concentrations as 14% lower than annual concentrations using a dataset of 82 dimictic lakes while Nurnberg (1998) shows a difference of 40% using a dataset of 127 stratified lakes. The mean observed concentration in Tom Pond (10 μg/L) is 20% lower than the predicted concentration (12 μg/L), which is within the range reported in the two Nurnberg studies.

**Table 3-5. Predicted In-lake Total Phosphorus Concentration using Empirical Models.**

| Empirical Equation | Equation | Predicted TP (*ug*/L) |
|---|---|---|
| Mass Balance | TP=L/(Z(F))*1000 | 17 |
| Kirchner-Dillon 1975 | TP=L(1-Rp)/(Z(F))*1000 | 12 |
| Vollenweider 1975 | TP=L/(Z(S+F))*1000 | 16 |
| Larsen-Mercier 1976 | TP=L(1-Rlm)/(Z(F))*1000 | 13 |
| Jones-Bachmann 1976 | TP=0.84(L)/(Z(0.65+F))*1000 | 13 |
| Reckhow General 1977 | TP=L/(11.6+1.2(Z(F)))*1000 | 9 |
| **Average of Above 5 Model Values** | | ***12*** |
| ***Observed Summer Epilimnion Mean (2001-2007)*** | | ***10*** |
| ***Observed Summer Epilimnion Median (2001-2007)*** | | ***10*** |

| Variable | Description | Units | Equation |
|---|---|---|---|
| L | Phosphorus Load to Lake | g P/m2/yr | |
| Z | Mean Depth | m | Volume/area |
| F | Flushing Rate | flushings/yr | Inflow/volume |
| S | Suspended Fraction | no units | Effluent TP/Influent TP |
| Qs | Areal Water Load | m/yr | Z(F) |
| Vs | Settling Velocity | m | Z(S) |
| Rp | Retention Coefficient (settling rate) | no units | ((Vs+13.2)/2)/(((Vs+13.2)/2)+Qs) |
| Rlm | Retention Coefficient (flushing rate) | no units | 1/(1+F^0.5) |

Once TP estimates were derived, annual mean chl *a* and SDT can be predicted based on another set of empirical equations: Carlson (1977), Dillon and Rigler (1974), Jones and Bachman (1976), Oglesby and Schaffner (1978), Vollenweider (1982), and Jones, Rast and Lee (1979). Bloom frequency was also calculated based on equations developed by Walker (1984, 2000) using a natural log mean chl *a* standard deviation of 0.5. These predictions are presented in Table 3-6. Predicted mean and peak chl *a* concentrations (Table 3-6) are considerably (about 60%) lower than those observed in the monitoring data (Table 2-2). This may be attributable to the presence of heterotrophic golden-brown algal species (NH DES, 2006b) that may be obtaining nutrients from sediment derived sources including bacteria and protozoa (Smith, 1950) in addition to water column sources.

**Table 3-6. Predicted In-lake Chlorophyll *a* and Secchi Disk Transparency Predictions based on an Annual Average In-lake Phosphorus Concentration of 12 μg/L.**

| Empirical Equation | Equation | Predicted Value |
|---|---|---|
| ***Mean Chlorophyll*** | | ***ug/L*** |
| Carlson 1977 | Chl=0.087*(Pred TP)^1.45 | 3.4 |
| Dillon and Rigler 1974 | Chl=10^(1.449*LOG(Pred TP)-1.136) | 2.8 |
| Jones and Bachmann 1976 | Chl=10^(1.46*LOG(Pred TP)-1.09) | 3.2 |
| Oglesby and Schaffner 1978 | Chl=0.574*(Pred TP)-2.9 | 4.2 |
| Modified Vollenweider 1982 | Chl=2*0.28*(Pred TP)^0.96 | 6.3 |
| **Average of Model Values** | | **4.0** |
| ***Observed Summer Mean (2001-2007)*** | | ***9.5*** |
| | | |
| ***Peak Chlorophyll*** | | ***ug/L*** |
| Modified Vollenweider (TP) 1982 | Chl=2*0.64*(Pred TP)^1.05 | 18.0 |
| Vollenweider (CHL) 1982 | Chl=2.6*(AVERAGE(Pred Chl))^1.06 | 11.3 |
| Modified Jones, Rast and Lee 1979 | Chl=2*1.7*(AVERAGE(Pred Chl))+0.2 | 13.7 |
| **Average of Model Values** | | **14.3** |
| ***Observed Summer Maximum (2001-2007)**** | | ***36.7*** |
| | | |
| ***Bloom Probability*** | | ***% of Summer*** |
| Probability of Chl >15 *u*g/L | See Walker 1984 & 2000 | 0.2% |
| | | |
| ***Secchi Transparency*** | | ***m*** |
| **Mean:** Oglesby and Schaffner 1978 | Chl=10^(1.36-0.764*LOG(Pred TP)) | 3.3 |
| **Max:** Modified Vollenweider 1982 | Chl=9.77*Pred TP^-0.28 | 4.8 |
| ***Observed Summer Mean (2001-2007)*** | | ***2.85*** |
| ***Observed Summer Maximum (2001-2007)*** | | ***3.75*** |
| | | |
| **Variable** | **Description** | **Units** |
| "Pred TP" | The average TP calculated from the 5 predictive equation models in Table 3-4 | *u*g/L |
| "Pred Chl" | The average of the 3 predictive equations calculating mean chlorophyll | *u*g/L |
| *The observed summer maximum is based on n=22 and is not necessarily the peak chlorophyll | | |

# 4.0 Total Maximum Daily Load

## 4.1 Maximum Annual Load

The annual load capacity is defined by the US EPA in 40 C.F.R. § 130.2(f) as, "The greatest amount of loading that a water can receive without violating water quality standards." The loading capacity is to be protective even during critical conditions, such as summertime conditions for TP loading to nutrient enriched lakes. The ENSR-LRM loading and lake response model was used to calculate the target annual TP load in (kg TP/yr) from the 12 $\mu$g/L target in-lake TP concentration discussed in Section 2.6. The TP loads that could practically be reduced were decreased until the target TP in-lake concentration was achieved. Further documentation of the ENSR-LRM model can be found in Appendix B.

The total maximum annual TP load that is expected to result in an in-lake annual mean TP concentration of 12 $\mu$g/L was estimated to be 33.5 kg/yr, which represents a 3% reduction from existing conditions (Table 4-1).

## 4.2 Maximum Daily Load

Although a daily loading timescale is not meaningful for ecological prediction or long-term watershed management of lakes, this TMDL will present daily pollutant loads of TP in addition to the annual load. US EPA believes that there is some flexibility in how the daily loads may be expressed (US EPA, 2006). Several of these options are presented in, "Options for Expressing Daily Loads in TMDLs" (US EPA, 2007).

The Tom Pond dataset and associated empirical model necessitates a statistical estimation of a maximum daily load because long periods of continuous simulation data and extensive flow and loading data are not available. US EPA (2007) provides such an approach.

The following expression assumes that loading data are log-normal distributed and is based on a long term mean load calculated by the empirical model and an estimation of the variability in loading.

$$MDL = LTA * e^{[z\sigma - 0.5\sigma^{\wedge}2]}$$

Where:

MDL = maximum daily limit
LTA = long-term average
Z = z-statistic of the probability of occurrence
$\sigma^2 = \ln(CV^2 + 1)$
CV= coefficient of variation

For the Tom Pond TMDL a coefficient of variation (CV) of 1.1 and a 95% probability level of occurrence (z = 1.64) were used. The CV was calculated as the mean of the CV of loading from 18 subwatersheds draining to Goose Pond and Bow Lake in New Hampshire (Schloss, 2008 unpublished data). The long term average (LTA) load of 0.09 kg/day was calculated by dividing the annual load (33.5 kg) by 365 days. The total maximum daily load of TP is 0.27 kg/day, or approximately 0.59 lbs/day.

## 4.3 Future Development

Since the human population within a watershed may continue to grow and contribute additional TP to the impaired lakes, TMDLs often include an allocation for growth and associated future TP loading. For example, in Maine, target TP loading from anticipated future development is equivalent to a 1.0 $\mu$g/L change in in-lake TP concentration (Dennis et al., 1992). However, the NH water quality regulation Env-Wq 1703.3(a) General Water Quality Criteria states, "The presence of pollutants in the surface waters shall not justify further introduction of pollutants from point and/or nonpoint sources". With regard to at least impaired waterbodies, it is the policy of NH DES that existing loads due to development are held constant, allowing no additional loading. In order for any future allocation of pollutant load(s) to be granted for an impaired waterbody, the load would need to be reduced elsewhere in the watershed. Given the antidegradation statement above (Section 2.4), this TMDL has been developed assuming no future increase in TP export from these impaired watersheds. However, it should be recognized that the NH DES has no mechanism for regulation/enforcement of TP export from developments of single house lots that do not require a Section 401 Water Quality Certification or fall under the thresholds for alteration of terrain permits (100,000 square feet of disturbance or 50,000 square feet within 250 feet of a lake). Municipalities can, however, regulate such development by revising their land use ordinances/regulations to require no additional loading of TP from new development.

## 4.4 Critical Conditions

Critical conditions in Tom Pond typically occur during the summertime, when the potential (both occurrence and frequency) for nuisance algal blooms are greatest. The loading capacity for TP was set to achieve desired water quality standards during this critical time period and also provide adequate protection for designated uses throughout the year. This was accomplished by using a target concentration based on summer epilimnetic data and applying it as a mean annual concentration in the predictive models used to establish the mean annual maximum load. Since summer epilimnetic values are typically about 20% less than mean annual concentrations (Nurnberg 1996, 1998), an annual load allocation based on mean annual concentrations will be sufficiently low to protect designated uses impacted by TP in the critical summer period.

## 4.5 Seasonal Variation

As explained in Section 4.4, the Tom Pond TMDL takes into account seasonal variations because the target annual load is developed to be protective of the most sensitive (i.e., biologically responsive) time of year (summer), when conditions most favor the growth of algae.

## 4.6 Reduction Needed

Current TP loading and in-lake concentrations are greater than required to support designated uses. The target TP concentration established in Section 2.6 was set in order to ensure that designated uses were supported. The degree of TP load reduction required to meet designated uses is calculated by subtracting the target load (Section 4.1) from the existing load estimated with ENSR-LRM (Section 3.3). Percent reductions are summarized in Table 4-1. Calculations are detailed in Table C-11 in Appendix C.

Using the estimated annual target load presented in Section 4.1, the TP load needs to be reduced to 33.5 kg/yr or a mean of 0.09 kg/d. Based on the daily analysis requirement discussed in Section 4.2, the maximum daily load should be <0.27 kg/d in order to meet the water quality target of 12 μg/L. This would require an overall reduction of 3% in the total load (including atmospheric, waterfowl, septic, and total watershed load). As some sources are less controllable than others, the actual reduction to be applied to achieve this goal will vary by source (see Section 5 TMDL Allocation). A 4% reduction from manageable watershed sources would be required to achieve the 12 μg/L target TP concentration. Alternative loading reduction scenarios are discussed further in Section 6.0 below.

**Table 4-1. Tom Pond Total Phosphorus Load at Target Criteria of 12 μg/L.**

| TP INPUTS | Modeled TP Load to Attain 12 *u*g/L Target (kg/yr) | Modeled Current TP Load (kg/yr) | Reduction (%) |
|---|---|---|---|
| Atmospheric | 3.3 | 3.3 | |
| Waterfowl | 0.8 | 0.8 | |
| Septic System | 5.6 | 5.6 | |
| Watershed Load-Direct Drainage | 23.7 | 24.8 | 4 |
| **TOTAL** | **33.5** | **34.5** | 3 |

## 4.7 TMDL Development Summary

There is currently no numerical water quality standard for TP in the State of New Hampshire. However, the relationship between TP and algal biomass is well documented in scientific literature. This TMDL was therefore developed for TP and is designed to protect Tom Pond and its designated uses impacted by excessive chl *a* concentrations.

To derive the numerical TP target concentration of 12 μg/L criteria, AECOM, the NH DES and EPA considered the following options: (1) examination of the distribution of TP concentrations in impaired and unimpaired lakes in New Hampshire; (2) use of nutrient levels for commonly-accepted trophic levels; and (3) use of probabilistic equations to establish targets to reduce risk of adverse conditions. All three approaches yield a similar target value. Because the first option uses data from New Hampshire lakes, it is viewed as the primary target setting method. The other two methods confirm the result of the first method, a target of 12 μg/L is appropriate. This target would lead to the desired low probability of algal blooms and a mean chl *a* level that supports all expected lake uses while incorporating a margin of safety (discussed in Section 5.2). Additional information regarding the three above listed approaches is documented in Appendix A.

In conclusion, water quality was linked to TP loading by:

- Choosing a preliminary target in-lake TP level, based on historic state-wide and in-lake water quality data, best professional judgment, and through consultation with NH DES and US EPA sufficient to attain water quality standards and support designated uses. The preliminary in-lake TP concentration target is 12 μg/L.
- Using the mean of five empirical models that link in-lake TP concentration and load, calibrated to lake-specific conditions, to estimate the load responsible for observed in-lake TP concentrations.
- Determining the overall mean annual in-lake TP concentration from those models, given that the observed in-lake concentrations may represent only a portion of the year or a specific location within the lake.
- Using the predicted mean annual in-lake TP concentration to predict Secchi disk transparency, chl *a* concentration and algal bloom frequency.
- Using the aforementioned empirical models to determine the TP load reduction needed to meet the numeric concentration target.
- Using a GIS-based spreadsheet model to provide a relative estimate of loads from watershed land areas and uses under current and various projected scenarios to assist stakeholders in developing TP reduction strategies.

Documentation of the model approach is presented in Appendix B. This approach is viewed as combining an appropriate level of modeling with the available water quality and watershed data to generate a reasonably reliable estimate of TP loading and concentration under historic, current, and potential future conditions. It offers a rational estimate of the direction and magnitude of change necessary to support the designated uses protected by New Hampshire.

# 5.0 TMDL Allocation

The allocations for the Tom Pond TMDL are expressed as both annual loads and daily loads. However, annual loads better align with the design and implementation of watershed and lake management strategies. The TMDL requires an allocation of the total load of the resource. The allocation includes a waste load allocation (WLA), load allocation (LA), and margin of safety (MOS). The sum of these allocations is equal to the target annual load or TMDL for the resource. Each of these allocations is defined in detail in the following subsections. Seasonal variation is also included in the loading allocations.

The equation for the Tom Pond TMDL analysis is as follows:

$$TMDL = LA + WLA + MOS$$

In the case of Tom Pond, the TMDL is equivalent to the target annual load of 33.5 kg/yr. Allocations of this load are described below.

## 5.1 Wasteload Allocations (WLAs) and Load Allocations (LAs)

Wasteload allocations identify the portion of the loading capacity that is allocated to point sources and load allocations identify the portion of the loading capacity that is allocated to nonpoint sources and natural background. Point sources in this watershed include stormwater outfalls and stormwater runoff from present or future construction activities. Nonpoint sources may include diffuse stormwater runoff, surface water base flow (including groundwater inseepage), septic systems, waterfowl, and atmospheric deposition. The real challenge in splitting out point sources from nonpoint sources resides with the available data. In order to accurately develop allocations for these two categories of sources it is essential to have not only a complete accounting of each point source, but also a delineation of the associated drainage area and an estimate of existing pollutant loading. Generating this loading estimate is further compounded by the fact that stormwater discharges are highly variable in frequency, duration, and quality. Because sufficient information at the parcel level was simply not available in this watershed, it is infeasible to draw a distinction between stormwater from existing or future regulated point sources, non-regulated point sources, and nonpoint sources. Therefore, a single wasteload allocation (WLA) has been set for the entire watershed, which includes both point and nonpoint sources (Table 6-1). This allocation is also expressed as a percent reduction (Table 6-1). This is the reduction needed from all controllable sources in order to ensure that designated uses are fully supported in this waterbody.

## 5.2 Margin of Safety (MOS)

An MOS in this TMDL accounts for substantial uncertainty in inputs to the models. In addition, the empirical equations used to predict in-lake TP concentrations, mean and maximum chl *a*, SDT, and algal bloom probability also introduces variability into the predictions described in Section 3.5. See Appendix A for a discussion of the MOS for each of the three approaches used to set the target.

# 6.0 Evaluation of Alternative Loading Scenarios

The ENSR-LRM model was used to evaluate a number of alternative loading scenarios and the probable lake response to these loadings. These scenarios included:

- Current Loading
- Natural Environmental Background Loading
- Removal of Septic Load
- Current Load with Periodic Warner River Backflow
- Reduction of Watershed Loads to Meet 12 μg/L Target

The current loading scenario is discussed above in Section 3.0. Each scenario described below represents a change from the current loading scenario. The discussion of each scenario includes only the portions of the current loading scenario that were altered for the specific simulation. A comparison of the results of each of the alternative scenarios is presented in Tables 6-1 and 6-2. More detailed model output can be found in Tables C-8 to C-11 in Appendix C.

**Table 6-1. Comparison of Phosphorus Loading Scenarios for Tom Pond.**

| **Inputs** | **Current Load (kg/yr)** | **Natural Environmental Background (kg/yr)** | **Current Load without Septic Load (kg/yr)** | **Current Load with Periodic Warner River Backflow (kg/yr)** | **Target Load (WLA) to Obtain 12 *ug*/L In-lake Concentration (kg/yr)** |
|---|---|---|---|---|---|
| Atmospheric | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 |
| Waterfowl | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 |
| Septic System | 5.6 | 0.0 | 0.0 | 5.6 | 5.6 |
| Watershed Load- Direct Drainage | 24.8 | 11.5 | 24.8 | 24.8 | 23.7 |
| Warner River Backflow | 0.0 | 0.0 | 0.0 | 32.5 | 0.0 |
| **Total Load** | 34.5 | 15.6 | 28.9 | 67.0 | 33.5 |
| ***Total Overall Load Reduction*** | 0.0 | 19.0 | 5.6 | N/A | 1.1 |
| ***Percent Overall Reduction*** | 0% | 55% | 16% | N/A | 3% |
| **Total Watershed Load** | 24.8 | 11.5 | 24.8 | 24.8 | 23.7 |
| ***Total Watershed Reduction*** | 0 | 13.3 | 0.0 | 0.0 | 1.1 |
| ***Percent Watershed Reduction*** | 0% | 54% | 0% | 0% | 4% |

**Table 6-2. Lake Water Quality Response to Different Loading Scenarios for Tom Pond.**

| Parameters | Current Load | Natural Environmental Background | Current Load without Septic Load | Current Load with Periodic Warner River Backflow | Target Load to Obtain 12 *u*g/L In-lake Concentration |
|---|---|---|---|---|---|
| TP Load (kg/yr) | 34.5 | 15.6 | 28.9 | 67.0 | 33.5 |
| Mean Annual TP (*u*g/L) | 12.4 | 5.5 | 10.4 | 24.1 | 12.0 |
| Mean Secchi Disk Transparency (m) | 3.3 | 6.2 | 3.8 | 2.0 | 3.4 |
| Mean Chlorophyll *a* (*u*g/L) | 4 | 1.2 | 3.1 | 9.5 | 3.8 |
| Peak Chlorophyll *a* (*u*g/L) | 14.3 | 5.0 | 11.5 | 32.3 | 13.8 |
| Probability of Summer Bloom (Chl *a* > 15 *u*g/L) | 0.2% | 0.00% | 0.0% | 12.2% | 0.1% |

## 6.1 Natural Environmental Background Phosphorus Loading

Natural environmental background levels of TP in the lake were evaluated using the ENSR-LRM model. Natural background was defined as background TP loading from non-anthropogenic sources. Hence, land uses in the watershed were set to its assumed “natural” state of forests and wetlands. Loading was then calculated using the ENSR-LRM model as described above. This estimate is useful as it sets a realistic lower bound of TP loading and in-lake concentrations possible for Tom Pond. Loadings and target concentrations below these levels are very unlikely to be achieved.

The septic loads were removed and all developed land was converted to forests. The developed land was split into mixed, deciduous, and coniferous forest categories in the same percentages as the current watershed forest composition. Waterfowl loading was not reduced as the waterfowl population is currently low and it is assumed natural. Wetland areas were not changed because it was assumed no wetland had been lost due to development. Background TP loads under this scenario were 15.6 kg/yr total with a watershed load of 11.5 kg/yr. Table 6-2 compares loads for possible scenarios. The calculated background loading of TP to Tom Pond would result in mean in-lake TP concentration of 5.5 μg/L, a mean Secchi Disk transparency of 6.2 m, and a bloom probability of chl *a* > 15 μg/L of 0%. Estimated TP loading to the lake under this scenario is 55% lower than current loads to the lake (Table 6-1). The lake would support designated uses under this scenario as in-lake predicted TP concentration (5.5 μg/L) is well below the target value (12 μg/L).

## 6.2 Septic System Load Removal

This scenario involved removal of the septic loads only. It is a reasonable approximation of what would occur if the lake were sewered or all existing septic systems exported TP at a negligible concentration. Under this scenario, total loading is decreased by 16% over current loading and would likely support designated uses because the predicted in-lake concentration at this scenario is 10 μg/L, which is below the target of 12 μg/L. Removal of all septic sources would likely be costly and may not be feasible. Also, note that our analysis did not account for actively failing septic systems, so the load may be underestimated. Such systems may have localized impacts on TP and should be addressed as they are discovered. It is recommended that a detailed septic survey be conducted in order to refine the septic system loading estimate in this model before widescale reduction measures are implemented.

## 6.3 Periodic Backflow from Warner River

This scenario attempts to estimate the influence of periodic backflow from the Warner River due to flooding. The model was calibrated to the mean summer chl *a* in order to predict the contribution of periodic Warner River flooding. This predictive scenario has limitations because the relationship between TP and chl *a* in Tom

Pond is not typical (there is much more chlorophyll *a* than can be explained by average annual TP concentrations). Under this scenario algal cells could be directly introduced in the river backflow or rapidly settled TP could be introduced and then subsequently taken up from the sediment surface by heterotrophic or motile algal species. The empirical relationships (Section 3.5) predict that the mean in-lake TP would have to be 24.1 μg/L in order to obtain the mean chl *a* concentrations observed in Tom Pond. It is possible that TP concentrations are elevated in spring when backflow occurs, but the monitoring data does not reflect this because the monitoring occurs in the summer (June-August). As previously mentioned, it is recommended that an early spring and summer study be conducted to determine the relationship between Warner River flooding and Tom Pond in-lake chl *a* and TP. Calculations are detailed in Appendix Table C-10.

## 6.4 Reduction of Loads to Meet In-lake Target of 12 μg/L

This scenario involves the focus of resources on the largest source of TP to Tom Pond, the watershed load. Under this scenario, watershed TP loads were iteratively reduced until predicted in-lake concentrations met the 12 μg/L target. A reduction of 4% of the loads from the watershed would be required to meet the annual load of 33.5 kg/yr related to the TMDL. A reduction of only 4% should be technologically achievable as it is much less than the maximum estimated achievable reduction of approximately 60-70% (Center for Watershed Protection, 2000). Loads associated with this scenario are presented in Table 6-1 and predicted in-lake concentrations and bloom probabilities are presented in Table 6-2. Calculations are detained in Appendix Table C-11.

# 7.0 Implementation Plan

The following TP control implementation plan provides recommendations for future BMP work and necessary water quality improvements. The recommendations are intended to provide options of potential watershed and lake management strategies that can improve water quality to meet target loads. Note that providing a comprehensive diagnostic/feasibility study is beyond the scope of this report, but we have attempted to narrow the range of management options in accordance with known loading issues and desired loading reductions.

The successful implementation of this TMDL will be based on compliance with water quality criteria in Env-Wq 1700 for planktonic chl *a* and not on meeting the TP reduction target (3%). It is anticipated that TP reductions associated with this TMDL will be conducted in phases.

As discussed in Section 3.3, watershed TP loading is the predominant source (72%) of TP to Tom Pond. The second largest source is septic systems (16%). Waterfowl also contribute to the total load, but if these sources were removed, the annual TP load would be reduced only by 2% (Sections 6.2). Implementing BMPs to reduce the watershed load and/or implementing measures to reduce septic system loading may be effective strategies to reduce the TP loading into Tom Pond in order to attain an in-lake TP concentration of 12 μg/L. As more data become available, estimates of septic system TP loading and potential reductions can be refined. However, if the source of the high chl *a* is due to the spring flooding of the Warner River (Section 3.2 and 6.3), then watershed or septic reduction may not result in Tom Pond supporting the use of primary contact recreation based on meeting criteria for chl *a*. A study is recommended to determine the influence of the Warner River and compare this load to the watershed and septic system TP loads.

Experience suggests that aggressive implementation of watershed BMPs may result in a maximum practical TP loading reduction of 60-70%. The actual reduction in watershed loading necessary to meet the 12 μg/L limit is 4% and it is assumed that this reduction would be obtained mainly from the runoff portion of the load. Implementation would be phased in over a period of several years, with monitoring and adjustment as necessary.

There are a number of BMPs that could appropriately be implemented in the Tom Pond watershed (Table 7-1). BMPs fall into three main functional groups: 1) Recharge / Infiltration Practices, 2) Low Impact Development Practices, and 3) Extended Detention Practices. The table lists the practices, the pollutants typically removed and the degree of effectiveness for each type of BMP. Specific information on the BMPs is well summarized by the Center for Watershed Protection (2000).

Some of these practices may be directly applicable to the Tom Pond watershed. The natural wetlands in the watershed naturally function to slow runoff water thereby encouraging infiltration of water and removal of TP through settling, soil adsorption and plant uptake. These functions should be preserved.

Detention practices can improve the quality of storm water originating from the highways and developments in the Tom Pond watershed. Stormwater from the Interstate 89 exit and Route 103 enters Tom Pond. Designing and installing BMPs that encourage infiltration or stormwater detention would reduce channel erosion and reduce TP concentrations by settling and contact with the soil prior to entry to the lake.

Retrofitting developed land with low impact designs is a highly desirable option, especially near the lake. Some homes are very close to the lake and provide little vegetated buffer. Educational programs can help raise the awareness of homeowners and inform them how they can alter drainage on their property to reduce nutrients entering the lake. Another option to engage the community is through technical assistance programs, such as BMP training for municipal officials and septic system inspection programs. Guidelines for evaluating TP export to lakes are found in, "Phosphorus Control in Lake Watersheds: A Technical Guide to Evaluating New Development" (Dennis et al., 1992). Recent guidance for low impact living on the shoreline, “Landscaping at the Waters Edge: An Ecological Approach”, has been developed by UNH Cooperative Extension (2007).

Section 319 of the Clean Water Act was established to assist states in nonpoint source control efforts. Under Section 319, grant money can be used for technical assistance, financial assistance, education training, technology transfer, demonstration projects and monitoring to assess the success of specific nonpoint source implementation projects,

US EPA has identified a minimum of nine elements that must be included in a management plan for achieving improvements in water quality. A summary of the nine elements is provided below. The full description can be found in US EPA (2005).

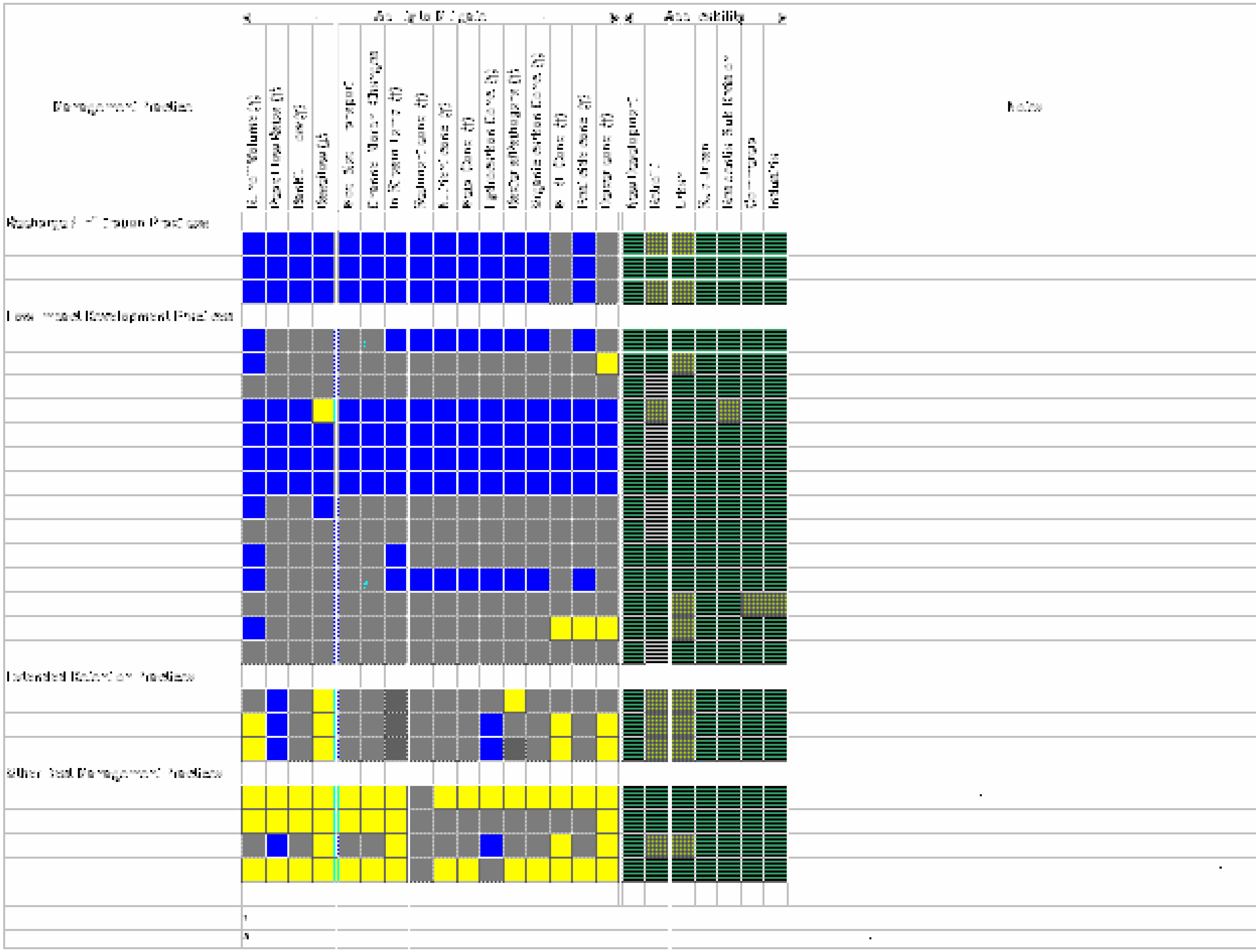
1) Identification of causes of impairment and pollutant sources.
2) An estimate of the load reductions expected from management measures.
3) A description of the nonpoint source measures needed to achieve load reductions.
4) An estimate of the technical and financial assistance needed and the cost.
5) An information and education component.
6) A schedule for implementation.
7) Description of milestones to determine if goals are being met.
8) Criteria to determine progress in reducing loads.
9) Monitoring to evaluate effectiveness of implementation efforts over time.

This TMDL was written to meet the criteria of the first element. Application materials and instructions for 319 funding can be obtained through:

Nonpoint Coordinator
New Hampshire Department of Environmental Services
29 Hazen Drive
P.O. Box 95
Concord, NH 03302
www.des.state.nh.us/wmb/was/grants.htm

Proactive planning can prevent the further degradation of lake water quality. However, past resistance to zoning regulations creates difficulties for proactive planning. The TMDL process is intended to give a direction and goal for planning and watershed management. As the lake improves, the implementation strategy should be re-evaluated using current data and modeling and the plan for further load reduction adapted accordingly.

**Table 7-1. Best Management Practices Selection Matrix.**



**Key**

- Adverse Impact
- Moderate Mitigation
- Good Mitigation
- Minimal Mitigation
- Moderately Suited
- Well Suited
- Not Applicable

# 8.0 Monitoring Plan

The New Hampshire Department of Environmental Services (NH DES) conducted water quality monitoring of Tom Pond in 1980, 1998 (NH DES, 1998), and 2006 for Lake Trophic Studies. The Volunteer Lake Assessment Program (VLAP) began in 1987 and continues to the present day (NH DES, 2006b) The deepest site in the center of the lake is the primary in-lake sampling location in Tom Pond (Figure 8-1). Water quality samples collected during summer stratification are tested for epilimnetic and hypolimnetic TP. In addition, a composite sample of the water column to the depth of the thermocline is tested for chl *a*. A DO profile from top to bottom is conducted and a Secchi disk transparency measurement is taken.

It is recommended that VLAP sampling be continued to document the in-lake response, trends, and compliance with water quality criteria following implementation of TP reduction measures. As discussed in the previous section, successful implementation of this TMDL will be based on compliance with water quality criteria for planktonic chl *a*. Data collected by VLAP includes DO, planktonic chl *a* and the reporting of cyanobacteria scums and should continue. NH DES staff will continue to sample and document the extent and severity of reported cyanobacteria scums through microscopic identification, cell counts and toxicity tests.

It is also recommended that an early spring and summer study be conducted to determine the relationship between Warner River flooding and Tom Pond in-lake chl *a* and TP. Warner River spring flooding may introduce additional TP or algal cells into the system and the TP may be retained by the outlet wetland or by the bottom sediments. Heterotrophic phytoplankton, such as the golden-brown, *Dinobryon spp*., found in Tom Pond (NH DES, 2006b), may be stimulated by this retained TP and organic matter or be feeding on bacteria or protozoa (Smith, 1950) which may partially explain the abnormally high chl *a* concentrations observed in summer. The linkage between the Warner River flooding, the algal community heterotrophy and/or nutrient transport should be further investigated in Tom Pond.

A survey of septic systems and groundwater monitoring would help confirm model input, including the assumption that there are no failed septic systems.

Implementation of the monitoring plan is contingent on the availability of sufficient staff and funding.

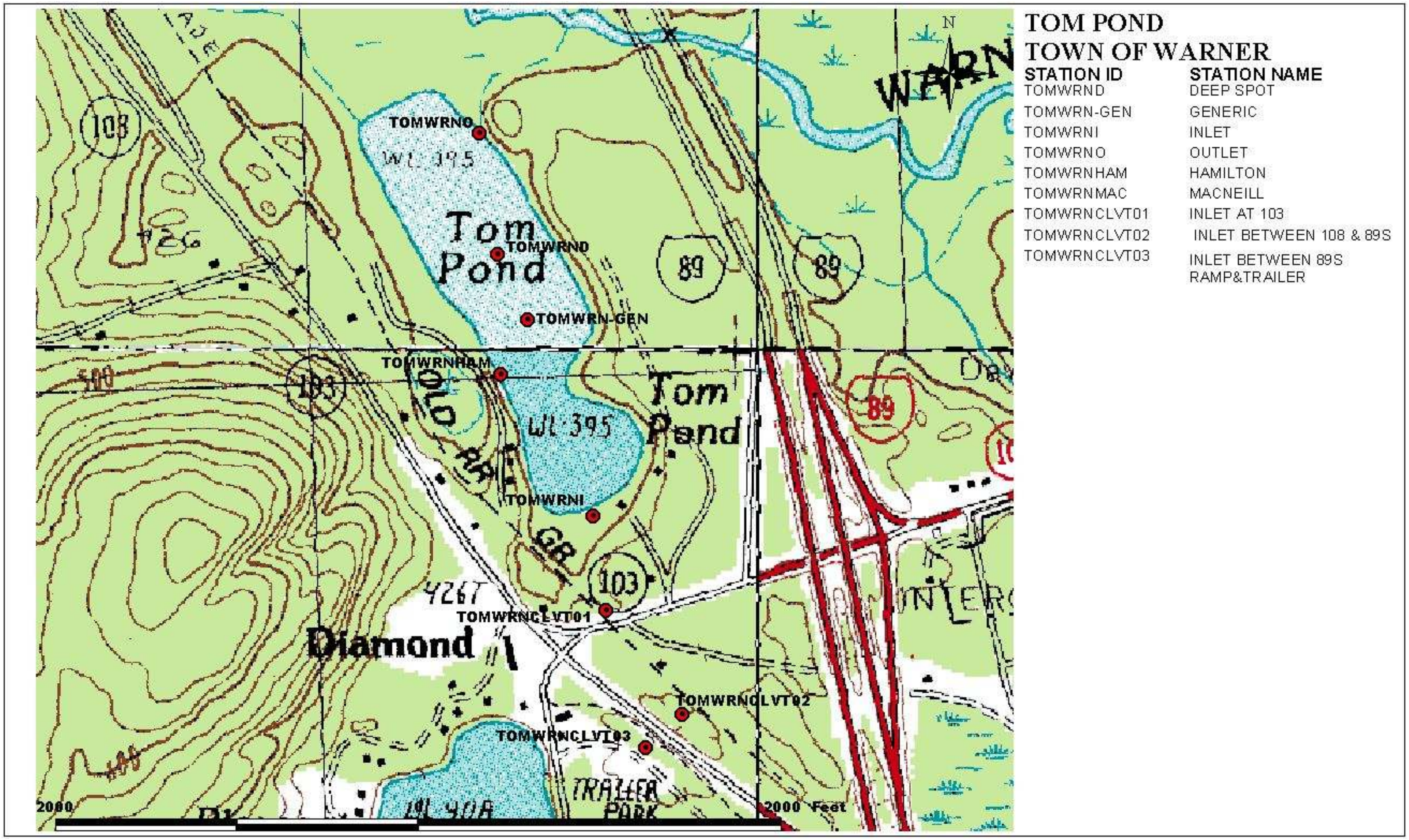



**Figure 8-1. NH DES Sampling Locations in Tom Pond.**

# 9.0 Reasonable Assurances

The TMDL provides reasonable assurances that nonpoint source reductions will occur by providing information on the cooperative efforts of the NH DES and watershed stakeholders to initiate the process of addressing nonpoint source pollution in the watershed. The successful reduction in nonpoint TP loading, however, depends on the willingness and motivation of stakeholders to get involved and the availability of federal, state, and local funds.

As discussed in section 5.1, sufficient data are simply not available in this watershed to draw an accurate distinction between nonpoint watershed sources and point sources of phosphorus. Given the difficulty in accurately separating these sources, the allocations in this TMDL are characterized as a single wasteload allocation (WLA) which includes both point and nonpoint sources. The State fully acknowledges that it will take a concerted effort to reduce phosphorus loading to the maximum extent practicable from as many sources as possible in order to fully support designated uses in this waterbody. In many cases, phosphorus reductions from individual sources can and should be greater than the prescribed reductions in this TMDL, in order to make up for areas of the watershed where greater reductions are not attainable.

Reasonable assurance that non-regulated point source and nonpoint source load reductions will occur include the following:

-RSA 485-A:12, which requires persons responsible for sources of pollution that lower the quality of waters below the minimum requirements of the classification to abate such pollution, will be enforced.

-NHDES will work with watershed stakeholders to identify specific phosphorus sources within the watershed. Technical assistance is available to mitigate phosphorus export from existing nonpoint sources. Requests for 319 funding to implement specific BMPs within the watershed shall receive high priority. The new NHDES Stormwater Manual provides information on site design techniques to minimize the impact of development on water quality as well as BMPs for erosion and sediment control and treatment of post-construction stormwater pollutants. Also of use to municipalities is the Innovative Land Use Planning Techniques Handbook, which provides model municipal ordinances including one on post-construction stormwater management. Both documents are accessible on the NHDES website at www.des.nh.gov. DES staff also provides assistance by working with Lake Associations to identify LID projects that would qualify for 319 funding.

-Per RSA 483-A:7 Lakes Management and Protection Plans, the lakes coordinator and the Office of Energy and Planning, in cooperation with regional planning agencies, and appropriate council on resources and development agencies, shall provide technical assistance and information in support of lake management and local shoreland planning efforts consistent with the guidelines established under RSA 483-A:7, and compatible with the criteria established under RSA 483-A:5.

-For lakes included in the NHDES Volunteer Lake Assessment Program, NHDES staff will meet with participants on an annual basis during field sampling visits and annual workshops to discuss TP reduction opportunities and assist them with securing 319 grants where eligible.

# 10.0 Public Participation

US EPA regulations (40 CFR 130.7 (c) (ii)) require that calculations to establish TMDLs be subject to public review.

A description of the public participation process and response to public comments will be provided after the public comment period for this TMDL has ended.

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# Appendix A:

# Methodology for Determining Target Criteria

## 1.0 Derivation of Total Phosphorus (TP) Target Values

As part of its contract with the US EPA, Region 1, AECOM is assisting the NH DES in developing Total Maximum Daily Loads (TMDLs) for 30 nutrient-impaired waterbodies in New Hampshire, under *Task 1, Development of Lake Phosphorus TMDLs*. To develop TMDLs for these waterbodies it is necessary to derive numeric total phosphorus (TP) target values (e.g., in-lake concentrations) for determining acceptable watershed nutrient loads. The background, approach, and TP target values are provided below.

### 1.1 Regulatory Background

As part of the national Nutrient Strategy originally set forth by the "Clean Water Action Plan" (US EPA, 1998), US EPA has directed the States to promulgate nutrient criteria or alternative means to address and reduce the effects of elevated nutrients (eutrophication) in lakes and ponds, reservoirs, rivers and streams, and wetlands. Where available, these nutrient criteria can be useful in developing TMDLs as well as in demonstrating potential compliance due to the implementation strategy selected to reduce impairment.

At this time, New Hampshire has not established a numeric water quality standard (or nutrient criterion) for TP to protect the designated water uses. Rather, New Hampshire has established a series of use-specific assessment criteria that are used to identify and list waters for impairment of designated uses under the unified Clean Water Act (CWA) Section 305(b) and Section 303(d) Consolidated Assessment and Listing Methodology (CALM) (NH DES, 2008a). Thus, while the 30 lakes considered by this investigation are considered likely to be impacted by excessive nutrients, the specific listed impairments are for the phytoplankton primary photopigment chlorophyll *a* (chl *a*) and the presence of cyanobacteria (indicator for primary contact recreation) and/or dissolved oxygen (DO) (indicator for aquatic life support) (NH DES, 2006a, 2008b).

#### 1.1.1 New Hampshire Water Use Assessment Criteria

The following assessment criteria have been established for evaluation compliance with water use support and for reporting and identifying waterbodies for listing on the unified CWA Section 305(b)/303(d) list in New Hampshire:

##### 1.1.1.1 Chlorophyll *a*

Assessment for the trophic indicator photopigment chl *a* is evaluated through comparison of samples generally collected during the summer index period (defined as May 24 – September 15) to the freshwater chl *a* interim criterion of 15 ppb (0.015 mg/L) (NH DES, 2008a). If the criterion is exceeded then the waterbody is considered non-supporting for the primary contact recreation water use.

##### 1.1.1.2 Dissolved Oxygen

Applicable water quality standards for DO include the following:

Env-Wq 1703.07 (b): Except as naturally occurs, or in waters identified in RSA 485-A:8, III, or subject to (c) below, class B waters shall have a DO content of at least 75% of saturation, based on a daily mean, and an instantaneous minimum DO concentration of at least 5 mg/L.

Env-Wq 1703.07 (d): Unless naturally occurring or subject to (a) above, surface waters within the top 25 percent of depth of thermally unstratified lakes, ponds, impoundments and reservoirs or within the epilimnion shall contain a DO content of at least 75 percent saturation, based on a daily mean and an instantaneous minimum DO content of at least 5 mg/L. Unless naturally occurring, the DO content below those depths shall be consistent with that necessary to maintain and protect existing and designated uses.

#### 1.1.1.3 Cyanobacteria

A lake is listed as not supporting primary contact recreation if cyanobacteria scums are present. Reduction of TP loading will reduce the likelihood of scum formation.

### 1.1.2 Linkage of Assessment Criteria to TP TMDLs

The chl *a,* cyanobacteria and DO assessment criteria described above provide NH DES with a consistent and efficient means to identify and list impaired waters for purposes of 305(b)/303(d). However, these parameters are not amenable to development of a TMDL for correction of these impairments for several reasons including:

- these are merely secondary indicators of eutrophication but not the primary cause (i.e., excessive nutrients);
- measurement of these parameters is complicated by physical (e.g., light availability) and temporal considerations (e.g., pre-dawn measurements);
- it is not feasible to establish watershed load allocations for chl *a* or DO;
- there are limited control technologies or best management practices (BMPs) for these parameters; and/or
- it is much more technically and economically feasible to address the primary cause (i.e., excessive nutrients) as a means to reduce or eliminate impairments.

While AECOM uses the term “excessive nutrients” as the primary cause, it is generally understood, and for purposes of this TMDL development assumed that, TP is the limiting nutrient for plant growth in these waters. Therefore, it is necessary to derive numeric TP target values that are both protective of the water uses and correlate to lake conditions under which the chl *a,* the presence of cyanobacteria scums and DO assessment criteria are met. TP is used as a surrogate for impairments related to chl *a*, cyanobacteria scums and DO.

## 1.2 Proposed TP TMDL Target Values

According to the 40 CFR Part 130.2, the TMDL for a waterbody is equal to the sum of the individual loads from point sources (i.e., wasteload allocations or WLAs), and load allocations (LAs) from nonpoint sources (including natural background conditions). Section 303(d) of the CWA also states that the TMDL must be established at a level necessary to implement the applicable water quality standards with seasonal variations and a margin of safety (MOS) which takes into account any lack of knowledge concerning the relationship between effluent limitations and water quality. In equation form, a TMDL may be expressed as follows:

$$\mathbf{TMDL = WLA + LA + MOS}$$

Where:

| | |
|---|---|
| WLA = | Waste Load Allocation (i.e., loadings from point sources); |
| LA = | Load Allocation (i.e., loadings from nonpoint sources including natural background); and |
| MOS = | Margin of Safety. |

TMDLs can be expressed in terms of either mass per time, toxicity or other appropriate measure [40 CFR, Part 130.2 (i)). However, in light of legal action, the US EPA has issued guidance that TMDLs should be expressed on a daily timescale to meet the wording of the legislation that created the program. Yet for lakes, daily nutrient loading limits are of little use in management, as lakes integrate loading over a much longer time period to manifest observed conditions. Expression of nutrient loads on seasonal to annual time scales is appropriate, although daily loads will be reported to meet program guidelines.

The MOS can be either explicit or implicit. If an explicit MOS is used, a portion of the total target load is allocated to the MOS. If the MOS is implicit, a specific value is not assigned to the MOS. Use of an implicit MOS may be appropriate when assumptions used to develop the TMDL are believed to be so conservative that they sufficiently account for the MOS.

### 1.3 Potential approaches to Derivation of TP target values.

While the need for development of nutrient criteria for lakes is well-documented, there is no clear consensus among the States or federal agencies regarding the best means to accomplish this goal, due to the complexity in defining precisely what concentrations will be protective of waterbodies' water quality as well as their designated uses. Some of the more common approaches include:

- Use of NH DES water quality recommendations;
- Use of nutrient levels for commonly accepted trophic levels; and
- Use of probabilistic equations to establish targets to reduce risk of adverse conditions.

#### 1.3.1 Target based on population of NH lakes

In the *Lake and Reservoir Technical Guidance Manual* (US EPA, 2000a), the US EPA provided a statistical approach for determining nutrient criteria that was subsequently used to develop a set of ecoregion-specific ambient water quality recommendations that were issued in 2000-2001 (US EPA, 2000b; US EPA 2000c).

The US EPA approach consists of selecting a pre-determined percentile from the distribution of measured variables from either (1) known reference lakes, (i.e., the highest quality or least impacted lakes) or (2) general population of lakes including both impaired and non-impaired lakes. The US EPA defined reference lakes as those representative of the least impacted conditions or what was considered to be the most attainable conditions for lakes within a state or ecoregion.

NH DES used a similar statistical approach when developing preliminary TP criteria for freshwaters in New Hampshire (NH DES, 2005). The NH DES evaluation identified statistically significant relationships between chl *a* and TP for lakes. Statistical relationships were based on: 1) the median of TP samples taken at one-third the water depth in unstratified lakes and at the mid-epilimnion depth in stratified lakes; and 2) the median of composite chl *a* samples of the water column to the mid-metalimnion depth in stratified lakes and to the two-thirds water depth in unstratified lakes during the summer months (June through September). A total of 168 lakes were included in the analysis of which 23 were impaired for chl *a* (i.e., lakes with chl *a* greater than or equal to 15 μg/L). Of the 23 impaired lakes, approximately 14 were stratified (60%) and 9 were unstratified (40%).

Figure A-2 shows the cumulative frequency plots for the impaired and non-impaired lakes. Based on Figure A-2, an initial TP target of 11.5 μg/L was selected. As shown, 20% of the impaired lakes and 80% of the non-impaired lakes have TP concentrations $\leq$ 11.5 μg/L which means that 20% of the non-impaired lakes have TP concentrations $\geq$ 11.5 μg/L). After rounding, a target of 12 μg/L strikes a reasonable balance between the percent of lakes that are impaired at concentrations below this level and the percent of lakes that are not impaired at concentrations above this concentration. A value of 12 μg/L is very similar to TP targets set by other methods discussed below.

Setting the TMDL based on an in-lake target concentration of 12 μg/L includes an implicit MOS for the following reasons. As discussed above, the target of 12 μg/L is primarily based on summer epilimnetic concentrations. This TMDL, however, is based on empirical models that predict mean annual TP lake concentrations assuming fully mixed conditions. Studies on other lakes indicate that mean annual concentrations can be 14% to 40% higher than summer epilimnetic concentrations (Nurnberg 1996, 1998). A value of 15 μg/L could have been used in the models to predict the TMDL. However, in order to include an

MOS, 12 µg/L was used. By setting the target equal to 12 µg/L in the models used to determine the TMDL, an implicit MOS of approximately 20% is provided.

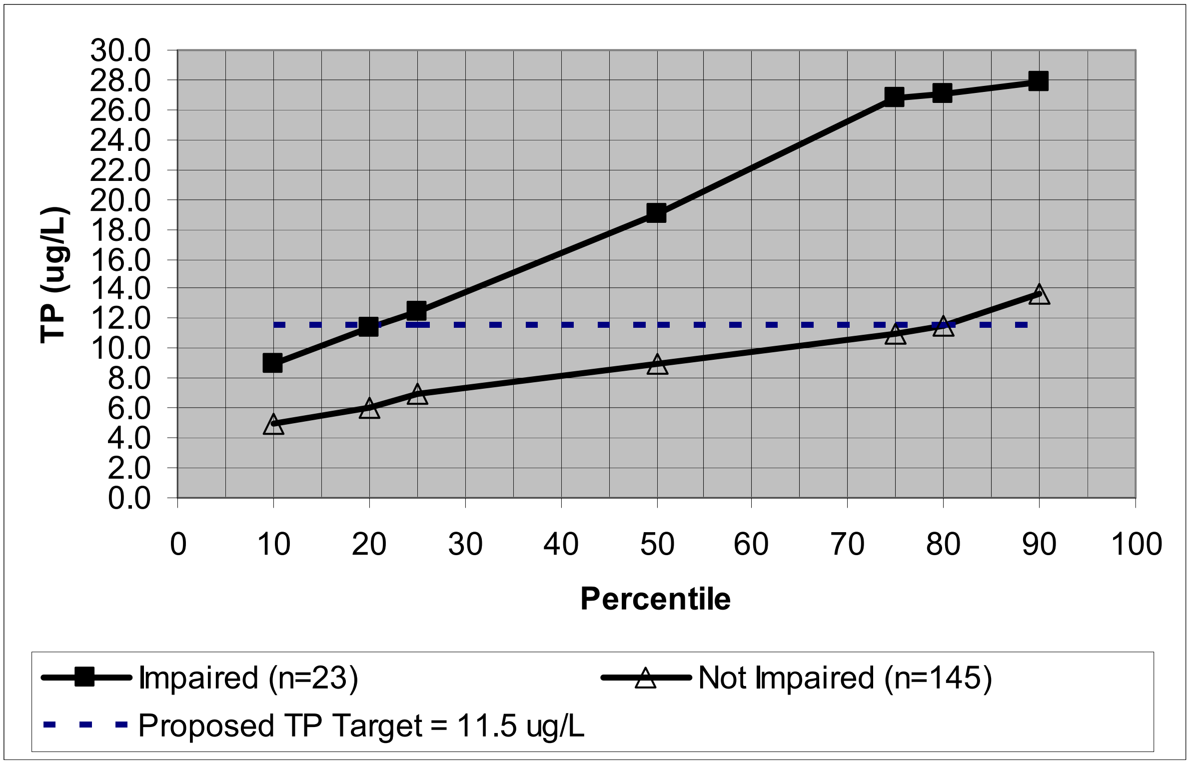


**Figure A-2: Cumulative Frequency Distribution of TP Concentrations in Impaired and Unimpaired New Hampshire Lakes.**

### 1.3.2 Trophic State Classification of Water bodies

Trophic state is an alternative means of setting a TP target concentration. One of the more powerful paradigms in limnology is the concept and classification of lakes as to their so-called trophic state. A trophic state classification is typically based on a generally recognized set or range of chemical concentrations and physical and biological responses. Lakes are generally classified as oligotrophic, mesotrophic, or eutrophic; the three states representing a gradient between least affected to most impacted waterbodies. Classification is based on the proximity of a lake's chemistry and biology to the list of characteristic for a specific trophic type. Classification may be based on both quantitative (e.g., chemical concentrations, turbidity) and/or qualitative factors (e.g., presence of pollution-tolerant species, aesthetic appearance).

While this system is widely accepted, there is no consensus regarding the absolute nutrient or trophic parameter value that defines a waterbody trophic state, although some guidelines have been suggested (US EPA, 1999). Indeed, it should be remembered that classification of lakes into the categories produces an arbitrary difference among lakes that may show very little differences in nutrient concentration. Despite its limitations, the trophic state concept is easily understood and widely used by limnologists, lake associations, state agencies, etc., to classify lakes and manage lakes. Further, it can be used as an indirect means of linking impairment of designated uses with critical nutrient levels or threshold values (i.e., the transition from one trophic state to another is likely associated with effects on designated uses).

To provide a means of quantifying the decision-making about trophic classification, waterbodies may be classified according to the Carlson Trophic State Index (TSI), a widely used indicator of trophic state (Carlson 1977). Carlson's TSI is an algal biomass-based index that relates the relationship between trophic parameters to levels of lake productivity. The TSI method provides three equations relating log-transformed concentrations of TP, chl *a*, and SDT to algal biomass, resulting in three separate TSI scores (e.g., TSI(TP), TSI(chl *a*), TSI(SDT)). The three equations are scaled such that the same TSI value should be obtained for a lake regardless of what parameter is used. Comparison of the results of the TSI system to more traditional trophic state classification identified TSI scores that are associated with the transition from one trophic state to another (Carlson, 1977).

For purposes of comparison, we initially used a system assuming thresholds or criteria for the transition from an oligotrophic to a mesotrophic state (estimated as a TSI value of 35) and for transition from a mesotrophic state to a eutrophic state (estimated as a TSI value of 50). The selected TSI thresholds are based on general lake attributes and are not specific to the New England ecoregions. However, Table A-2 represents a first approximation of the range of trophic indicators assigned to a trophic state.

**Table A-2. Trophic Status Classification based on water quality variables**

| Variables | Oligotrophic (TSI < 30) | Mesotrophic ($30 \le$ TSI < 50) | Eutrophic (TSI > 50) |
|---|---|---|---|
| TP ($\mu$g/L) | <10 | 10-24 | >24 |
| Chl *a* ($\mu$g/L) | <1.5 | 1.5-7.2 | >7.2 |
| SDT (m) | >6 | 2-6 | <2 |

It can be seen that the NH criterion for chl *a* (15 $\mu$g/L) will generally not be exceeded by a lake having a mesotrophic status (chl *a* of 1.5 – 7.2 $\mu$g/L). In most cases, mesotrophic conditions are also supportive of all aquatic life conditions. It can also be seen that the proposed NH criterion of 12 $\mu$g/L TP discussed in Section 1.3.1 will place the lake in the mesotrophic category. However, the ranges of concentrations considered by this approach are relatively large and alternative numeric criteria could be used equally as well. Accordingly, development or refinement based on ecoregion-specific information regarding trophic response and/or protection of designated uses was used to refine these ranges.

Based on our inspection of the water quality and biotic responses of the 30 New Hampshire lakes of this study, it appears that these lakes are more responsive to inputs of TP than the general class of national lakes that Carlson considered in devising his classes. For example, AECOM considers it likely that allowing > 20 μg/L TP for an in-lake surface concentration will result in eutrophic lake conditions in these lakes and uses that contention as justification to narrow the range of appropriate mean concentrations to 10-20 μg/L. The midpoint of this range is approximately 15 μg/L. An annual mean concentration of 15 μg/L TP is also coincidentally the threshold value for mesotrophic lakes used by the New Hampshire Lay Lakes Monitoring Program (LLMP) (Craycraft and Schloss, 2005).

The trophic status classification is assumed to be based on mean annual TP. However, most water quality samples are taken during summer conditions. Total algal growth is typically predicted from spring turnover TP values, which tend to be higher by approximately 20% on mean (Nurnberg, 1996, 1998). Therefore, using a TP target of 20% lower than 15 μg/L would more appropriately predict the actual potential chl *a*. An implicit MOS of 20% would result in a target concentration for Tom Pond of 12 μg/L.

### 1.3.3. Probabilistic Approach to Setting TP Target Goal

Target TP goals can also be determined using a probabilistic approach that aims at reducing the level and frequency of deleterious algal blooms (as indicated by chl *a* levels). The concept is to set a TP criterion that achieves a desired probability (i.e., risk) level of incurring an algal bloom in a lake system. Based on the level of acceptable risk or how often a system can experience an exceedance of an adverse condition (in this case defined as a chl *a* level of 15 μg/L), the TP criterion is selected.

Water quality modeling performed by Walker (1984, 2000) provides a means to calculate the TP level associated with any set level of exceedance of any set target level. For these TMDLs, the goal is to minimize the potential risk of exceedance of 15 μg/L chl *a* (summer algal bloom), but not place the criterion so low that it could not realistically be achieved due to TP contributions from natural background conditions. The corresponding TP concentration is used as the basis for developing target TMDLs, although not as the final target TP value, since it incorporates no MOS factor and does not account for uncertainty in the TP loading and concentration estimates.

Based on our analysis of Tom Pond, the TP concentration of 12 μg/L corresponded to a potential risk of exceedance of 15 μg/L chl *a* in summer of 0.1%, consistent with the target value of 12 μg/L derived in Section 1.3.2 above and suggesting that a TP value close to 12 μg/L would lead to the desired low probability of summer algal blooms and a mean chl *a* level that will support all expected lake uses.

For this method, the MOS is implicit due to conservative assumptions because the Walker bloom probability model is based on summer water quality data. However, the TP concentrations predicted by the ENSR-LRM model are annual mean concentrations which are typically higher than summer values. Applying the bloom probability model to annual mean concentrations rather than lower summer concentrations will result in an overestimate of the probability of blooms occurring in the summer.

## 1.4 Summary of Derivation of TP Target Goal

As part of its US EPA/NH DES contract for developing TMDLs for 30 nutrient-impaired New Hampshire waterbodies, AECOM developed an approach and rationale for deriving numeric TP target values for determining acceptable watershed nutrient loads. These TP target values are protective of the water uses and correlate to lake conditions under which the existing New Hampshire chl *a*, cyanobacteria, and DO assessment criteria are met.

To derive these criteria, AECOM considered the following options: (1) examination of the distribution of TP concentrations in impaired and unimpaired lakes in New Hampshire; (2) use of nutrient levels for commonly-accepted trophic levels; and (3) use of probabilistic equations to establish targets to reduce risk of adverse conditions. All three approaches yield a similar target value. Because the first option uses data from New Hampshire lakes, it is viewed as the primary target setting method. The other two methods confirm the result of the first method, a target of 12 μg/L is appropriate. This target would lead to the desired low probability of algal blooms and a mean chl *a* level that supports all expected lake uses. Based on the data that went in the data for these analyses, there is an MOS of approximately 20%.

For watersheds that do not have permitted discharges such as MS4 systems (i.e., WLA = 0), the LA term simplifies to the amount of watershed TP load needed to produce a modeled in-lake concentration of 12 μg/L. Urban watersheds will need to account for the influence of stormwater when determining acceptable loads.

Based on the above discussion, a target value of 12 μg/L TP will be used to establish target TP loading for the 30 nutrient New Hampshire TMDLs. However there are a few exceptions:

- If modeling indicates that TP loadings under "natural" conditions will result in TP concentrations greater than 12 μg/L, then the TMDL target will be set equal to the modeled TP concentration corresponding to the all natural loading scenario for that lake. There is no need, nor is it usually feasible, to reduce loadings below those occurring under natural conditions. Furthermore, state surface water quality standards allow exceedances of criteria (i.e, targets) if they are due to naturally occurring conditions. For example, Env-Wq 1703.14 (b) states the following:

"Class B waters shall contain no TP or nitrogen in such concentrations that would impair any existing or designated uses, unless naturally occurring."

- If observed monitoring data indicates actual chl *a* violations are occurring in the lake at TP concentrations less than 12 μg/L, then the target shall be set equal to either 1) the median concentration of the sampling data with a 20% reduction to incorporate an MOS (or another percent reduction determined appropriate for that particular lake) or 2) to the modeled concentration corresponding to background (i.e. natural) conditions.

# Appendix B:

# ENSR-LRM Methodology Documentation

# APPENDIX B:
# LLRM – Lake Loading Response Model Users Guide
# (also called SHEDMOD or ENSR-LRM)

**Model Overview**

The Lake Loading Response Model, or LLRM, originated as a teaching tool in a college course on watershed management, where it was called SHEDMOD. This model has also been historically called ENSR-LRM. The intent was to provide a spreadsheet program that students could use to evaluate potential consequences of watershed management for a target lake, with the goal of achieving desirable levels of phosphorus (TP), nitrogen (N), chlorophyll a (Chl) and Secchi disk transparency (SDT). For the NH Lake TMDLs only TP, Chl and SDT were simulated. As all cells in the spreadsheet are visible, the effect of actions could be traced throughout the calculations and an understanding of the processes and relationships could be developed.

LLRM remains spreadsheet based, but has been enhanced over the years for use in watershed management projects aimed at improving lake conditions. It is still a highly transparent model, but various functions have been added and some variables have been refined as new literature has been published and experience has been gained. It is adaptable to specific circumstances as data and expertise permit, but requires far less of each than more complex models such as SWAT or BASINS. This manual provides a basis for proper use of LLRM.

**Model Platform**

LLRM runs within Microsoft Excel. It consists of three numerically focused worksheets within a spreadsheet:

1. Reference Variables – Provides values for hydrologic, export and concentration variables that must be entered for the model to function. Those shown are applicable to the northeastern USA, and some would need to be changed to apply to other regions.
2. Calculations – Uses input data to generate estimates of water, N and TP loads to the lake. All cells shaded in blue must have entries if the corresponding input or process applies to the watershed and lake. If site-specific values are unavailable, one typically uses the median value from the Reference Variables sheet.
3. Predictions – Uses the lake area and inputs calculated in the Calculations sheet to predict the long-term, steady state concentration of N, TP and Chl in the lake, plus the corresponding SDT. This sheet applies five empirical models and provides the average final results from them.

**Watershed Schematic**

Generation of a schematic representation of the watershed is essential to the model. It is not a visible part of the model, but is embodied in the routing of water and nutrients performed by the model and it is a critical step. For the example provided here, the lake and watershed shown in Figure 1 is modeled. It consists of a land area of 496.5 hectares (ha) and a lake with an area of 40 ha. There are two defined areas of direct drainage (F and G), from which water reaches the lake by overland sheetflow, piped or ditched stormwater drainage, or groundwater seepage (there are no tributaries in these two drainage basins). There is also a tributary (Trib 1) that is interrupted by a small pond, such that the corresponding watershed might best be represented as two parts, upstream and downstream of that pond, which will provide some detention and nutrient removal functions. There is another tributary (Trib 2) that consists of two streams that combine to form one that then enters the lake, the classic “Y’ drainage pattern. With differing land uses associated with each of the upper parts of the Y and available data for each near the confluence, this part of the watershed is best subdivided into three drainage areas. As shown in Figure 2, the watershed of Figure 1 is represented as the lake with two direct drainage units, a tributary with an upper and lower drainage unit, and a tributary with two upper and one lower drainage units. The ordering is important on several levels, most notably as whatever nutrient loading attenuation occurs in the two lower tributary basins will apply to loads generated in the corresponding upper basins. Loads are generated and may be managed in any of the drainage basins, but how they affect the lake will be determined by how those loads are processed on the way to the lake. LLRM is designed to provide flexibility when testing management scenarios, based on watershed configuration and the representation of associated processes.

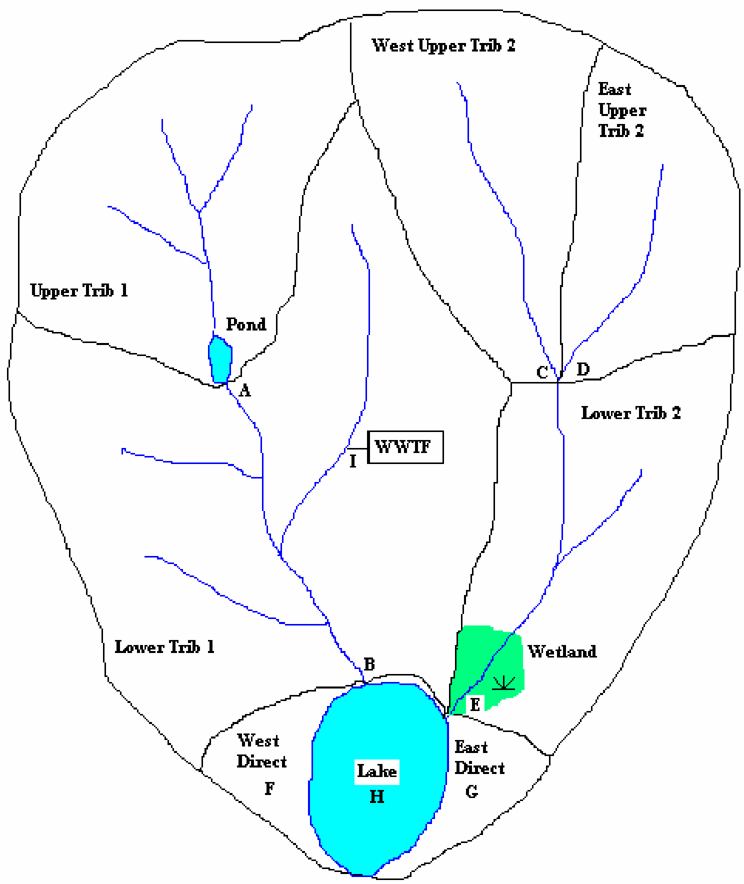


Figure 1. Watershed Map for Example System

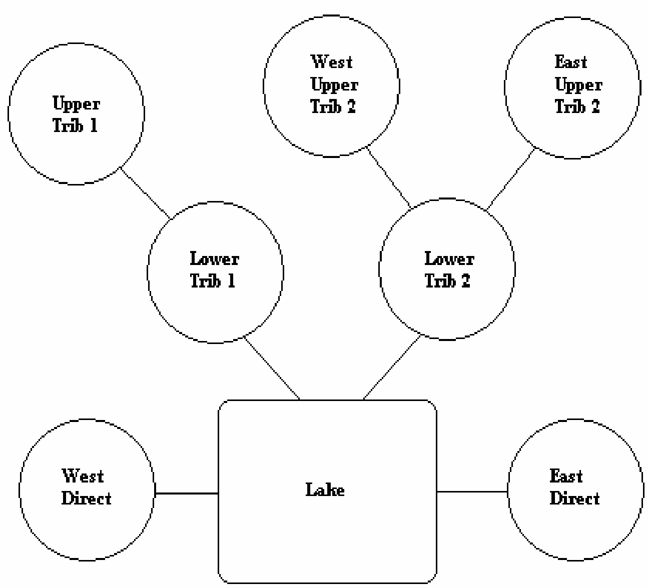


Figure 2. Watershed Schematic for Example System

**Model Elements**

There are three main types of inputs necessary to run LLRM:

1. Hydrology inputs – These factors govern how much water lands on the watershed and what portion is converted to runoff or baseflow. The determination of how much precipitation becomes runoff vs. baseflow vs. deep groundwater not involved in the hydrology of the target system vs. loss to evapotranspiration is very important, and requires some knowledge of the system. All precipitation must be accounted for, but all precipitation will not end up in the lake. In the northeast, runoff and baseflow may typically account for one to two thirds of precipitation, the remainder lost to evapotranspiration or deep groundwater that may feed surface waters elsewhere, but not in the system being modeled. As impervious surface increases as a percent of total watershed area, more precipitation will be directed to runoff and less to baseflow. There are two routines in the model to allow “reality checks” on resultant flow derivations, one using a standard areal water yield based on decades of data for the region or calculated from nearby stream gauge data, and the other applying actual measures of flow to check derived estimates.
2. Nutrient yields – Export coefficients for N and TP determine how much of each is generated by each designated land use in the watershed. These export values apply to all like land use designations; one cannot assign a higher export coefficient to a land use in one basin than to the same land use in another basin. Differences are addressed through attenuation. This is a model constraint, and is imposed partly for simplicity and partly to prevent varied export assignment without justification. Where differing export really does exist for the same land uses in different basins of the watershed, attenuation can be applied to adjust what actually reaches the lake. Nutrient export coefficients abound in the literature, and ranges, means and medians are supplied in the Reference Variables sheet. These are best applied with some local knowledge of export coefficients, which can be calculated from land area, flow and nutrient concentration data. However, values calculated from actual data will include attenuation on the way to the point of measurement. As attenuation is treated separately in this model, one must determine the pre-attenuation export coefficients for entry to initiate the model. The model provides a calculation of the export coefficient for the “delivered” load that allows more direct comparison with any exports directly calculated from data later in the process.
3. Other nutrient inputs – five other sources of N and TP are recognized in the model:
   a. Atmospheric deposition – both wet and dry deposition occur and have been well documented in the literature. The area of deposition should be the entire lake area. Choice of an export coefficient can be adjusted if real data for precipitation and nutrient concentrations is available.
   b. Internal loading – loads can be generated within the lake from direct release from the sediment (dissolved TP, ammonium N), resuspension of sediment (particulate TP or N) with possible dissociation from particles, or from macrophytes (“leakage” or scenescence). All of these modes have been studied and can be estimated with a range, but site specific data for surface vs. hypolimnetic concentrations, pre-stratification whole water column vs. late summer hypolimnetic concentrations, changes over time during dry periods (limited inflow), or direct sediment measures can be very helpful when selecting export coefficients.
   c. Waterfowl and other wildlife – Inputs from various bird species and other water dependent wildlife (e.g., beavers, muskrats, mink or otter) have been evaluated in the literature. Site specific data on how many animals use the lake for how long is necessary to generate a reliable estimate.
   d. Point sources – LLRM allows for up to three point sources, specific input points for discharges with known quantity and quality. The annual volume, average concentration, and basin where the input occurs must be specified.
   e. On-site wastewater disposal (septic) systems – Septic system inputs in non-direct drainage basins is accounted for in baseflow export coefficients, but a separate process is provided for direct drainage areas where dense housing may contribute disproportionately. The number of houses in two zones (closer and farther away, represented here as <100 ft and 100-300 ft from the lake) can be specified, with occupancy set at either seasonal (90 days) or year round (365 days). For the NH lake nutrient TMDLs, one zone of 125 feet from the lake was used. The number of people per household, water use per person per day, and N and TP concentrations and attenuation factors must be specified. Alternatively, these inputs can be accounted for in the baseflow export coefficient for direct drainage areas if appropriate data are available, but this module allows estimation from what is often perceived as a potentially large source of nutrients.

LLRM then uses the input information to make calculations that can be examined in each corresponding cell, yielding wet and dry weather inputs from each defined basin, a combined total for the watershed, a summary of other direct inputs, and total loads of TP and N to the lake, with an overall average concentration for each as an input level. Several constraining factors are input to govern processes, such as attenuation, and places to compare actual data to derived estimates are provided. Ultimately, the lake area and loading values are transferred to the Prediction sheet where, with the addition of an outflow TP concentration and lake volume, estimation of average in-lake TP, N, Chl and SDT is performed. The model is best illustrated through an example, which is represented by the watershed in Figures 1 and 2. Associated tables are directly cut and pasted from the example model runs.

**Hydrology**

Water is processed separately from TP and N in LLRM. While loading of water and nutrients are certainly linked in real situations, the model addresses them separately, then recombines water and nutrient loads later in the calculations. This allows processes that affect water and nutrient loads differently (e.g., many BMPs) to be handled effectively in the model.

**Water Yield**

Where a cell is shaded, an entry must be made if the corresponding portion of the model is to work. For the example watershed, the standard yield from years of data for a nearby river, to which the example lake eventually drains, is 1.6 cubic feet per square mile (cfsm) as shown below. That is, one can expect that in the long term, each square mile of watershed will generate 1.6 cubic feet per second (cfs). This provides a valuable check on flow values derived from water export from various land uses later in the model.

| **COEFFICIENTS** | |
|---|---|
| STD. WATER YIELD (CFSM) | 1.6 |
| PRECIPITATION (METERS) | 1.21 |

**Precipitation**

The precipitation landing on the lake and watershed, based on years of data collected at a nearby airport, is 1.21 m (4 ft, or 48 inches) per year, as shown above. Certainly there will be drier and wetter years, but this model addresses the steady state condition of the lake over the longer term.

**Runoff and Baseflow Coefficients**

Partitioning coefficients for water for each land use type have been selected from literature values and experience working in this area. Studies in several of the drainage basins to the example lake and for nearby tributaries outside this example system support the applied values with real data. It is expected that the sum of export coefficients for runoff and baseflow will be <1.0; some portion of the precipitation will be lost to deep groundwater or evapotranspiration.

| | RUNOFF EXPORT COEFF. | | | BASEFLOW EXPORT COEFF. | | |
|---|---|---|---|---|---|---|
| | Precip | P Export | N Export | Precip | P Export | N Export |
| | Coefficient | Coefficient | Coefficient | Coefficient | Coefficient | Coefficient |
| LAND USE | (Fraction) | (kg/ha/yr) | (kg/ha/yr) | (Fraction) | (kg/ha/yr) | (kg/ha/yr) |
| Urban 1 (Residential) | 0.30 | 0.65 | 5.50 | 0.15 | 0.010 | 5.00 |
| Urban 2 (Roads) | 0.40 | 0.75 | 5.50 | 0.10 | 0.010 | 5.00 |
| Urban 3 (Mixed Urban/Commercial) | 0.60 | 0.80 | 5.50 | 0.05 | 0.010 | 5.00 |
| Urban 4 (Industrial) | 0.50 | 0.70 | 5.50 | 0.05 | 0.010 | 5.00 |
| Urban 5 (Parks, Recreation Fields, Institutional) | 0.10 | 0.80 | 5.50 | 0.05 | 0.010 | 5.00 |
| Agric 1 (Cover Crop) | 0.15 | 0.80 | 6.08 | 0.30 | 0.010 | 2.50 |
| Agric 2 (Row Crop) | 0.30 | 1.00 | 9.00 | 0.30 | 0.010 | 2.50 |
| Agric 3 (Grazing) | 0.30 | 0.40 | 5.19 | 0.30 | 0.010 | 5.00 |
| Agric 4 (Feedlot) | 0.45 | 224.00 | 2923.20 | 0.30 | 0.010 | 25.00 |
| Forest 1 (Upland) | 0.10 | 0.20 | 2.86 | 0.40 | 0.005 | 1.00 |
| Forest 2 (Wetland) | 0.05 | 0.10 | 2.86 | 0.40 | 0.005 | 1.00 |
| Open 1 (Wetland/Lake) | 0.05 | 0.10 | 2.46 | 0.40 | 0.005 | 0.50 |
| Open 2 (Meadow) | 0.05 | 0.10 | 2.46 | 0.30 | 0.005 | 0.50 |
| Open 3 (Excavation) | 0.40 | 0.80 | 5.19 | 0.20 | 0.005 | 0.50 |
| Other 1 | 0.10 | 0.20 | 2.46 | 0.40 | 0.050 | 0.50 |
| Other 2 | 0.35 | 1.10 | 5.50 | 0.25 | 0.050 | 5.00 |
| Other 3 | 0.60 | 2.20 | 9.00 | 0.05 | 0.050 | 20.00 |

Setting export coefficients for the division of precipitation between baseflow, runoff and other components (deep groundwater, evapotranspiration) that do not figure into this model is probably the hardest part of model set-up. Site specific data are very helpful, but a working knowledge of area hydrology and texts on the subject is often sufficient. This is an area where sensitivity testing is strongly urged, as some uncertainly around these values is to be expected. There is more often dry weather data available for tributary streams than wet weather data, and some empirical derivation of baseflow coefficients is recommended. Still, values are being assigned per land use category, and most basins will have mixed land use, so clear empirical validation is elusive. As noted, sensitivity testing by varying these coefficients is advised to determine the effect on the model of the uncertainty associated with this difficult component of the model.

**Nutrient Yields for Land Uses**

**Phosphorus and Nitrogen in Runoff**

The values applied in the table above are not necessarily the medians from the Reference Variables sheet, since there are data to support different values being used here. There may be variation across basins that is not captured in the table below, as the same values are applied to each land use in each basin; that is a model constraint. Values for “Other” land uses are inconsequential in this case, as all land uses are accounted for in this example watershed without creating any special land use categories. Yet if a land use was known to have strong variation among basins within the watershed, the use of an “Other” land use class for the strongly differing land use in one or another basin could incorporate this variability.

**Phosphorus and Nitrogen in Baseflow**

Baseflow coefficients are handled the same way as for runoff coefficients above. While much of the water is likely to be delivered with baseflow, a smaller portion of the TP and N loads will be delivered during dry weather, as the associated water first passes through soil. In particular, TP is removed effectively by many soils, and transformation of nitrogen among common forms is to be expected.

The table above is commonly adjusted to calibrate the model, but it is important to justify all changes. Initial use of the median TP export value for a land use may be based on a lack of data or familiarity with the system, and when the results strongly over- or under-predict actual in-lake concentrations, it may be necessary to adjust the export value for one or more land use categories to achieve acceptable agreement. However, this should not be done without a clear understanding of why the value is probably higher or lower than represented by the median; the model should not be blindly calibrated, and field examination of conditions that affect export values is strongly recommended.

## Other Nutrient Inputs

### Atmospheric Deposition

Both wet and dry deposition nutrient inputs are covered by the chosen values, and are often simple literature value selections. Where empirical data for wet or dry fall are available, coefficients should be adjusted accordingly. Regional data are often available and can be used as a reality check on chosen values. Choices of atmospheric export coefficients are often based on dominant land use in the contributory area (see Reference Variables sheet), but as the airshed for a lake is usually much larger than the watershed, it is not appropriate to use land use from the watershed as the sole criterion for selecting atmospheric export coefficients. Fortunately, except where the lake is large and the watershed is small, atmospheric inputs tend not to have much influence on the final concentrations of TP or N in the lake, so this is not a portion of the model on which extreme investigation is usually necessary.

For the example system, a 40 ha lake is assumed to receive 0.2 kg TP/ha/yr and 6.5 kg N/ha/yr, the median values from the Reference Variables sheet. The model then calculates the loads in kg/yr to the lake and uses them later in the summary.

| **AREAL SOURCES** | Affected Lake Area (ha) | P Export Coefficient (kg/ha/yr) | N Export Coefficient (kg/ha/yr) | P Load (from coeff) (kg/yr) | N Load (from coeff) (kg/yr) | Period of Release (days) | P Rate of Release (mg/m2/day) | N Rate of Release (mg/m2/day) | P Load (from rate) (kg/yr) | N Load (from rate) (kg/yr) |
|---|---|---|---|---|---|---|---|---|---|---|
| Direct Atmospheric Deposition | 40 | 0.20 | 6.50 | 8 | 260 | | | | | |
| Internal Loading | 20 | 2.00 | 5.00 | 40 | 100 | 100 | 2.00 | 5.00 | 40 | 100 |

### Internal Loading

Internal release of TP or N is generally described as a release rate per square meter per day. It can be a function of direct dissolution release, sediment resuspension with some dissociation of available nutrients, or release from rooted plants. The release rate is entered as shown in the table above, along with the affected portion of the lake, in this case half of the 40 ha area, or 20 ha. The period of release must also be specified, usually corresponding to the period of deepwater anoxia or the plant growing season. The model then calculates a release rate as kg/ha/yr and a total annual load as shown in the table above.

For the NH lake nutrient TMDLs, the release rate from internal loading was calculated using water quality data (pre-stratification vs. late summer hypolimnetic TP concentrations or late summer hypolimnetic vs. late summer epilimnetic TP concentrations) and dividing by the anoxic area of the lake.

### Waterfowl or Other Wildlife

Waterfowl or other wildlife inputs are calculated as a direct product of the number of animal-years on the lake (e.g., 100 geese spending half a year = 50 bird-years) and a chosen input rate in kg/animal/yr, as shown in the table below. Input rates are from the literature as shown in the Reference Variables sheet, while animal-years must be estimated for the lake.

| **NON-AREAL SOURCES** | Number of Source Units | Volume (cu.m/yr) | P Load/Unit (kg/unit/yr) | N Load/Unit (kg/unit/yr) | P Conc. (ppm) | N Conc. (ppm) | P Load (kg/yr) | N Load (kg/yr) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Waterfowl | 50 | | 0.20 | 0.95 | | | 10 | 47.5 | | |
| Point Sources | | | | | | | | | | |
| PS-1 | | 45000 | | | 3.00 | 12.00 | 135 | 540 | | |
| PS-2 | | 0 | | | 3.00 | 12.00 | 0 | 0 | | |
| PS-3 | | 0 | | | 3.00 | 12.00 | 0 | 0 | | |
| Basin in which Point Source occurs (0=NO 1=YES) | | | | | | | | | | |
| | BASIN 1 | BASIN 2 | BASIN 3 | BASIN 4 | BASIN 5 | BASIN 6 | BASIN 7 | BASIN 8 | BASIN 9 | BASIN 10 |
| PS-1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| PS-2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| PS-3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

### Point Source Discharges

LLRM allows for three point source discharges. While some storm water discharges are legally considered point sources, the point sources in LLRM are intended to be daily discharge sources, such as wastewater treatment facility or cooling water discharges. The annual volume of the discharge must be entered as well as the average concentration for TP and TN, as shown in the table above. The model then calculates the input of TP and TN. It is also essential to note which basin receives the discharge, denoted by a 1 in the appropriate column. As shown in the table above, the example system has a discharge in Basin 4, and no discharges in any other basin (denoted by 0).

### On-Site Wastewater Disposal Systems

While the input from septic systems in the direct drainage areas around the lake can be addressed through the baseflow export coefficient, separation of that influence is desirable where it may be large enough to warrant management consideration. In such cases, the existing systems are divided into those within 100 ft of the lake and those between 100 and 300 ft of the lake, each zone receiving potentially different attenuation factors. For the NH lake TMDLs, a single 125 foot zone was used. A further subdivision between dwelling occupied all year vs. those used only seasonally is made. The number of people per dwelling and the water use per person per day are specified, along with the expected concentrations of TP and TN in septic system effluent, as shown in the table below. The model then calculates the input of water, TP and TN from each septic system grouping. If data are insufficient to subdivide systems along distance or use gradients, a single line of this module can be used with average values entered.

| DIRECT SEPTIC SYSTEM LOAD | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Septic System Grouping (by occupancy or location) | Days of Occupancy/Yr | Distance from Lake (ft) | Number of Dwellings | Number of People per Dwelling | Water per Person per Day (cu.m) | P Conc. (ppm) | N Conc. (ppm) | P Attenuation Factor | N Attenuation Factor | Water Load (cu.m/yr) | P Load (kg/yr) | N Load (kg/yr) |
| Group 1 Septic Systems | 365 | <100 | 25 | 2.5 | 0.25 | 8 | 20 | 0.2 | 0.9 | 5703 | 9.1 | 102.7 |
| Group 2 Septic Systems | 365 | 100 - 300 | 75 | 2.5 | 0.25 | 8 | 20 | 0.1 | 0.8 | 17109 | 13.7 | 273.8 |
| Group 3 Septic Systems | 90 | <100 | 50 | 2.5 | 0.25 | 8 | 20 | 0.2 | 0.9 | 2813 | 4.5 | 50.6 |
| Group 4 Septic Systems | 90 | 100 - 300 | 100 | 2.5 | 0.25 | 8 | 20 | 0.1 | 0.8 | 5625 | 4.5 | 90.0 |
| | | | | | | | | | | | | |
| Total Septic System Loading | | | | | | | | | | 31250 | 31.8 | 517.0 |

### Subwatershed Functions

The next set of calculations addresses inputs from each defined basin within the system. Basins can be left as labeled, 1, 2, 3, etc., or the blank line between Basin # and Area (Ha) can be used to enter an identifying name. In this case, basins have been identified as the East Direct drainage, the West Direct drainage, Upper Tributary #1, Lower Tributary #1, East Upper Tributary #2, West Upper Tributary #2, and Lower Tributary #2, matching the watershed and schematic maps in Figures 1 and 2.

### Land Uses

The area of each defined basin associated with each defined land use category is entered, creating the table below. The model is set up to address up to 10 basins; in this case there are only seven defined basins, so the other three columns are left blank and do not figure in to the calculations. The total area per land use and per basin is summed along the right and bottom of the table. Three “Other” land use lines are provided, in the event that the standard land uses provided are inadequate to address all land uses identified in a watershed. It is also possible to split a standard land use category using one of the “Other” lines, where there is variation in export coefficients within a land use that can be documented and warrants separation.

Land use data is often readily available in GIS formats. It is always advisable to ground truth land use designation, especially in rapidly developing watersheds. The date on the land use maps used as sources should be as recent as possible.

| BASIN AREAS | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | BASIN 1 | BASIN 2 | BASIN 3 | BASIN 4 | BASIN 5 | BASIN 6 | BASIN 7 | BASIN 8 | BASIN 9 | BASIN 10 | TOTAL |
| | E. Direct | W. Direct | Upper T1 | Lower T1 | W. Upper T2 | E. Upper T2 | Lower T2 | | | | |
| LAND USE | AREA (HA) | AREA (HA) | AREA (HA) | AREA (HA) | AREA (HA) | AREA (HA) | AREA (HA) | AREA (HA) | AREA (HA) | AREA (HA) | AREA (HA) |
| Urban 1 (Residential) | 12.0 | 8.5 | 8.4 | 47.4 | 6.7 | 4.5 | 18.1 | | | | 105.5 |
| Urban 2 (Roads) | 3.7 | 5.5 | 0.0 | 5.9 | 0.8 | 0.6 | 2.3 | | | | 18.8 |
| Urban 3 (Mixed Urban/Commercial) | 3.6 | 5.8 | 0.0 | 5.9 | 0.8 | 0.6 | 2.3 | | | | 19.0 |
| Urban 4 (Industrial) | 0.0 | 0.0 | 0.0 | 23.5 | 0.0 | 0.0 | 0.0 | | | | 23.5 |
| Urban 5 (Parks, Recreation Fields, Institutional) | 0.0 | 3.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | | | | 3.2 |
| Agric 1 (Cover Crop) | 0.0 | 0.0 | 0.0 | 0.8 | 12.3 | 0.0 | 0.0 | | | | 13.1 |
| Agric 2 (Row Crop) | 0.0 | 0.0 | 0.0 | 0.0 | 16.2 | 0.0 | 0.0 | | | | 16.2 |
| Agric 3 (Grazing) | 0.0 | 0.0 | 0.0 | 0.0 | 4.0 | 0.0 | 0.0 | | | | 4.0 |
| Agric 4 (Feedlot) | 0.0 | 0.0 | 0.0 | 0.0 | 0.5 | 0.0 | 0.0 | | | | 0.5 |
| Forest 1 (Upland) | 7.7 | 17.5 | 50.3 | 90.3 | 9.2 | 32.0 | 33.6 | | | | 240.6 |
| Forest 2 (Wetland) | 0.0 | 0.2 | 0.0 | 14.5 | 0.0 | 0.0 | 1.9 | | | | 16.6 |
| Open 1 (Wetland/Lake) | 2.5 | 0.6 | 2.0 | 0.1 | 0.0 | 0.1 | 14.2 | | | | 19.4 |
| Open 2 (Meadow) | 2.0 | 1.3 | 0.0 | 10.2 | 0.1 | 0.0 | 0.2 | | | | 13.8 |
| Open 3 (Excavation) | 0.1 | 0.1 | 0.0 | 2.3 | 0.0 | 0.0 | 0.0 | | | | 2.5 |
| Other 1 | | | | | | | | | | | 0.0 |
| Other 2 | | | | | | | | | | | 0.0 |
| Other 3 | | | | | | | | | | | 0.0 |
| | | | | | | | | | | | |
| TOTAL | 31.6 | 42.6 | 60.7 | 200.9 | 50.6 | 37.7 | 72.4 | 0 | 0 | | 496.5 |

## Load Generation

At this point, the model will perform a number of calculations before any further input is needed. These are represented by a series of tables with no shaded cells, and include calculation of water, TP and TN loads from runoff and baseflow as shown below. These loads are intermediate products, not subject to attenuation or routing, and have little utility as individual values. They are the precursors of the actual loads delivered to the lake, which require some additional input information.

| WATER LOAD GENERATION: RUNOFF | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | BASIN 1 | BASIN 2 | BASIN 3 | BASIN 4 | BASIN 5 | BASIN 6 | BASIN 7 | BASIN 8 | BASIN 9 | BASIN 10 | TOTAL |
| | E. Direct | W. Direct | Upper T1 | Lower T1 | W. Upper T2 | E. Upper T2 | Lower T2 | | | | |
| LAND USE | (CU.M/YR) | (CU.M/YR) | (CU.M/YR) | (CU.M/YR) | (CU.M/YR) | (CU.M/YR) | (CU.M/YR) | (CU.M/YR) | (CU.M/YR) | (CU.M/YR) | (CU.M/YR) |
| Urban 1 (Residential) | 43560 | 30855 | 30492 | 172056 | 24182 | 16277 | 65563 | 0 | 0 | 0 | 382985 |
| Urban 2 (Roads) | 18005 | 26457 | 0 | 28676 | 4030 | 2713 | 10927 | 0 | 0 | 0 | 90808 |
| Urban 3 (Mixed Urban/Commercial) | 26136 | 42108 | 0 | 43014 | 6045 | 4069 | 16391 | 0 | 0 | 0 | 137763 |
| Urban 4 (Industrial) | 0 | 0 | 0 | 142175 | 0 | 0 | 0 | 0 | 0 | 0 | 142175 |
| Urban 5 (Parks, Recreation Fields, Institutional) | 0 | 3872 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3872 |
| Agric 1 (Cover Crop) | 0 | 0 | 0 | 1387 | 22325 | 0 | 0 | 0 | 0 | 0 | 23712 |
| Agric 2 (Row Crop) | 0 | 0 | 0 | 0 | 58806 | 0 | 0 | 0 | 0 | 0 | 58806 |
| Agric 3 (Grazing) | 0 | 0 | 0 | 0 | 14520 | 0 | 0 | 0 | 0 | 0 | 14520 |
| Agric 4 (Feedlot) | 0 | 0 | 0 | 0 | 2723 | 0 | 0 | 0 | 0 | 0 | 2723 |
| Forest 1 (Upland) | 9325 | 21175 | 60863 | 109263 | 11126 | 38720 | 40600 | 0 | 0 | 0 | 291073 |
| Forest 2 (Wetland) | 0 | 150 | 0 | 8746 | 0 | 0 | 1153 | 0 | 0 | 0 | 10049 |
| Open 1 (Wetland/Lake) | 1494 | 334 | 1210 | 56 | 0 | 37 | 8591 | 0 | 0 | 0 | 11722 |
| Open 2 (Meadow) | 1210 | 768 | 0 | 6199 | 38 | 0 | 122 | 0 | 0 | 0 | 8336 |
| Open 3 (Excavation) | 593 | 454 | 0 | 10991 | 0 | 0 | 0 | 0 | 0 | 0 | 12038 |
| Other 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Other 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Other 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | | | | | | | | | | |
| | | | | | | | | | | | |
| | | | | | | | | | | | |
| | | | | | | | | | | | |
| TOTAL (CU.M/YR) | 100323 | 126173 | 92565 | 522564 | 143794 | 61816 | 143347 | 0 | 0 | 0 | 1190582 |
| TOTAL (CFS) | 0.11 | 0.14 | 0.10 | 0.59 | 0.16 | 0.07 | 0.16 | 0.00 | 0.00 | 0.00 | 1.33 |

| WATER LOAD GENERATION: BASEFLOW | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | BASIN 1 | BASIN 2 | BASIN 3 | BASIN 4 | BASIN 5 | BASIN 6 | BASIN 7 | BASIN 8 | BASIN 9 | BASIN 10 | TOTAL |
| | E. Direct | W. Direct | Upper T1 | Lower T1 | W. Upper T2 | E. Upper T2 | Lower T2 | | | | |
| | (CU.M/YR) | (CU.M/YR) | (CU.M/YR) | (CU.M/YR) | (CU.M/YR) | (CU.M/YR) | (CU.M/YR) | (CU.M/YR) | (CU.M/YR) | (CU.M/YR) | (CU.M/YR) |
| Urban 1 (Residential) | 21780 | 15428 | 15246 | 86028 | 12091 | 8139 | 32781 | 0 | 0 | 0 | 191492 |
| Urban 2 (Roads) | 4501 | 6614 | 0 | 7169 | 1008 | 678 | 2732 | 0 | 0 | 0 | 22702 |
| Urban 3 (Mixed Urban/Commercial) | 2178 | 3509 | 0 | 3585 | 504 | 339 | 1366 | 0 | 0 | 0 | 11480 |
| Urban 4 (Industrial) | 0 | 0 | 0 | 14218 | 0 | 0 | 0 | 0 | 0 | 0 | 14218 |
| Urban 5 (Parks, Recreation Fields, Institutional) | 0 | 1936 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1936 |
| Agric 1 (Cover Crop) | 0 | 0 | 0 | 2775 | 44649 | 0 | 0 | 0 | 0 | 0 | 47424 |
| Agric 2 (Row Crop) | 0 | 0 | 0 | 0 | 58806 | 0 | 0 | 0 | 0 | 0 | 58806 |
| Agric 3 (Grazing) | 0 | 0 | 0 | 0 | 14520 | 0 | 0 | 0 | 0 | 0 | 14520 |
| Agric 4 (Feedlot) | 0 | 0 | 0 | 0 | 1815 | 0 | 0 | 0 | 0 | 0 | 1815 |
| Forest 1 (Upland) | 37301 | 84700 | 243452 | 437052 | 44504 | 154880 | 162402 | 0 | 0 | 0 | 1164291 |
| Forest 2 (Wetland) | 0 | 1203 | 0 | 69969 | 0 | 0 | 9220 | 0 | 0 | 0 | 80393 |
| Open 1 (Wetland/Lake) | 11953 | 2672 | 9680 | 450 | 0 | 294 | 68728 | 0 | 0 | 0 | 93777 |
| Open 2 (Meadow) | 7260 | 4605 | 0 | 37192 | 226 | 0 | 732 | 0 | 0 | 0 | 50016 |
| Open 3 (Excavation) | 297 | 227 | 0 | 5496 | 0 | 0 | 0 | 0 | 0 | 0 | 6019 |
| Other 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Other 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Other 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Point Source #1 | 0 | 0 | 0 | 45000 | 0 | 0 | 0 | 0 | 0 | 0 | 45000 |
| Point Source #2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Point Source #3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | | | | | | | | | | |
| TOTAL (CU.M/YR) | 85270 | 120894 | 268378 | 708932 | 178122 | 164330 | 277961 | 0 | 0 | 0 | 1803888 |
| TOTAL (CFS) | 0.10 | 0.14 | 0.30 | 0.79 | 0.20 | 0.18 | 0.31 | 0.00 | 0.00 | 0.000 | 2.02 |

| LOAD GENERATION: RUNOFF P | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | BASIN 1 | BASIN 2 | BASIN 3 | BASIN 4 | BASIN 5 | BASIN 6 | BASIN 7 | BASIN 8 | BASIN 9 | BASIN 10 | TOTAL |
| | E. Direct | W. Direct | Upper T1 | Lower T1 | W. Upper T2 | E. Upper T2 | Lower T2 | | | | |
| LAND USE | (KG/YR) | (KG/YR) | (KG/YR) | (KG/YR) | (KG/YR) | (KG/YR) | (KG/YR) | (KG/YR) | (KG/YR) | (KG/YR) | (KG/YR) |
| Urban 1 (Residential) | 7.8 | 5.5 | 5.5 | 30.8 | 4.3 | 2.9 | 11.7 | 0.0 | 0.0 | 0.0 | 68.6 |
| Urban 2 (Roads) | 2.8 | 4.1 | 0.0 | 4.4 | 0.6 | 0.4 | 1.7 | 0.0 | 0.0 | 0.0 | 14.1 |
| Urban 3 (Mixed Urban/Commercial) | 2.9 | 4.6 | 0.0 | 4.7 | 0.7 | 0.4 | 1.8 | 0.0 | 0.0 | 0.0 | 15.2 |
| Urban 4 (Industrial) | 0.0 | 0.0 | 0.0 | 16.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 16.5 |
| Urban 5 (Parks, Recreation Fields, Institutional) | 0.0 | 2.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2.6 |
| Agric 1 (Cover Crop) | 0.0 | 0.0 | 0.0 | 0.6 | 9.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 10.5 |
| Agric 2 (Row Crop) | 0.0 | 0.0 | 0.0 | 0.0 | 16.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 16.2 |
| Agric 3 (Grazing) | 0.0 | 0.0 | 0.0 | 0.0 | 1.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.6 |
| Agric 4 (Feedlot) | 0.0 | 0.0 | 0.0 | 0.0 | 112.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 112.0 |
| Forest 1 (Upland) | 1.5 | 3.5 | 10.1 | 18.1 | 1.8 | 6.4 | 6.7 | 0.0 | 0.0 | 0.0 | 48.1 |
| Forest 2 (Wetland) | 0.0 | 0.0 | 0.0 | 1.4 | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 | 1.7 |
| Open 1 (Wetland/Lake) | 0.2 | 0.1 | 0.2 | 0.0 | 0.0 | 0.0 | 1.4 | 0.0 | 0.0 | 0.0 | 1.9 |
| Open 2 (Meadow) | 0.2 | 0.1 | 0.0 | 1.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.4 |
| Open 3 (Excavation) | 0.1 | 0.1 | 0.0 | 1.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2.0 |
| Other 1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Other 2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Other 3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | | | | | | | | | | | |
| TOTAL | 15.6 | 20.6 | 15.7 | 79.4 | 147.1 | 10.2 | 23.6 | 0.0 | 0.0 | 0.0 | 312.2 |

| LOAD GENERATION: RUNOFF N | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | BASIN 1 | BASIN 2 | BASIN 3 | BASIN 4 | BASIN 5 | BASIN 6 | BASIN 7 | BASIN 8 | BASIN 9 | BASIN 10 | TOTAL |
| | E. Direct | W. Direct | Upper T1 | Lower T1 | W. Upper T2 | E. Upper T2 | Lower T2 | | | | |
| LAND USE | (KG/YR) | (KG/YR) | (KG/YR) | (KG/YR) | (KG/YR) | (KG/YR) | (KG/YR) | (KG/YR) | (KG/YR) | (KG/YR) | (KG/YR) |
| Urban 1 (Residential) | 66.0 | 46.8 | 46.2 | 260.7 | 36.6 | 24.7 | 99.3 | 0.0 | 0.0 | 0.0 | 580.3 |
| Urban 2 (Roads) | 20.5 | 30.1 | 0.0 | 32.6 | 4.6 | 3.1 | 12.4 | 0.0 | 0.0 | 0.0 | 103.2 |
| Urban 3 (Mixed Urban/Commercial) | 19.8 | 31.9 | 0.0 | 32.6 | 4.6 | 3.1 | 12.4 | 0.0 | 0.0 | 0.0 | 104.4 |
| Urban 4 (Industrial) | 0.0 | 0.0 | 0.0 | 129.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 129.3 |
| Urban 5 (Parks, Recreation Fields, Institutional) | 0.0 | 17.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 17.6 |
| Agric 1 (Cover Crop) | 0.0 | 0.0 | 0.0 | 4.6 | 74.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 79.4 |
| Agric 2 (Row Crop) | 0.0 | 0.0 | 0.0 | 0.0 | 145.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 145.8 |
| Agric 3 (Grazing) | 0.0 | 0.0 | 0.0 | 0.0 | 20.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 20.8 |
| Agric 4 (Feedlot) | 0.0 | 0.0 | 0.0 | 0.0 | 1461.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1461.6 |
| Forest 1 (Upland) | 22.0 | 50.1 | 143.9 | 258.3 | 26.3 | 91.5 | 96.0 | 0.0 | 0.0 | 0.0 | 688.0 |
| Forest 2 (Wetland) | 0.0 | 0.7 | 0.0 | 41.3 | 0.0 | 0.0 | 5.4 | 0.0 | 0.0 | 0.0 | 47.5 |
| Open 1 (Wetland/Lake) | 6.1 | 1.4 | 4.9 | 0.2 | 0.0 | 0.1 | 34.9 | 0.0 | 0.0 | 0.0 | 47.7 |
| Open 2 (Meadow) | 4.9 | 3.1 | 0.0 | 25.2 | 0.2 | 0.0 | 0.5 | 0.0 | 0.0 | 0.0 | 33.9 |
| Open 3 (Excavation) | 0.6 | 0.5 | 0.0 | 11.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 12.9 |
| Other 1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Other 2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Other 3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | | | | | | | | | | | |
| TOTAL | 139.9 | 182.0 | 195.0 | 796.6 | 1775.2 | 122.5 | 261.0 | 0.0 | 0.0 | 0.0 | 3472.2 |

| LOAD GENERATION: BASEFLOW P | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | BASIN 1 | BASIN 2 | BASIN 3 | BASIN 4 | BASIN 5 | BASIN 6 | BASIN 7 | BASIN 8 | BASIN 9 | BASIN 10 | TOTAL |
| | E. Direct | W. Direct | Upper T1 | Lower T1 | W. Upper T2 | E. Upper T2 | Lower T2 | | | | |
| LAND USE | (KG/YR) | (KG/YR) | (KG/YR) | (KG/YR) | (KG/YR) | (KG/YR) | (KG/YR) | (KG/YR) | (KG/YR) | (KG/YR) | (KG/YR) |
| Urban 1 (Residential) | 0.12 | 0.09 | 0.08 | 0.47 | 0.07 | 0.04 | 0.18 | 0.00 | 0.00 | 0.00 | 1.06 |
| Urban 2 (Roads) | 0.04 | 0.05 | 0.00 | 0.06 | 0.01 | 0.01 | 0.02 | 0.00 | 0.00 | 0.00 | 0.19 |
| Urban 3 (Mixed Urban/Commercial) | 0.04 | 0.06 | 0.00 | 0.06 | 0.01 | 0.01 | 0.02 | 0.00 | 0.00 | 0.00 | 0.19 |
| Urban 4 (Industrial) | 0.00 | 0.00 | 0.00 | 0.24 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.24 |
| Urban 5 (Parks, Recreation Fields, Institutional) | 0.00 | 0.03 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.03 |
| Agric 1 (Cover Crop) | 0.00 | 0.00 | 0.00 | 0.01 | 0.12 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.13 |
| Agric 2 (Row Crop) | 0.00 | 0.00 | 0.00 | 0.00 | 0.16 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.16 |
| Agric 3 (Grazing) | 0.00 | 0.00 | 0.00 | 0.00 | 0.04 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.04 |
| Agric 4 (Feedlot) | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 |
| Forest 1 (Upland) | 0.04 | 0.09 | 0.25 | 0.45 | 0.05 | 0.16 | 0.17 | 0.00 | 0.00 | 0.00 | 1.20 |
| Forest 2 (Wetland) | 0.00 | 0.00 | 0.00 | 0.07 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.08 |
| Open 1 (Wetland/Lake) | 0.01 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.07 | 0.00 | 0.00 | 0.00 | 0.10 |
| Open 2 (Meadow) | 0.01 | 0.01 | 0.00 | 0.05 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.07 |
| Open 3 (Excavation) | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 |
| Other 1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Other 2 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Other 3 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Point Source #1 | 0.00 | 0.00 | 0.00 | 135.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 135.00 |
| Point Source #2 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Point Source #3 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | | | | | | | | | |
| TOTAL | 0.25 | 0.33 | 0.35 | 136.42 | 0.46 | 0.22 | 0.48 | 0.00 | 0.00 | 0.00 | 138.50 |

| LOAD GENERATION: BASEFLOW N | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | BASIN 1 | BASIN 2 | BASIN 3 | BASIN 4 | BASIN 5 | BASIN 6 | BASIN 7 | BASIN 8 | BASIN 9 | BASIN 10 | TOTAL |
| | E. Direct | W. Direct | Upper T1 | Lower T1 | W. Upper T2 | E. Upper T2 | Lower T2 | | | | |
| LAND USE | (KG/YR) | (KG/YR) | (KG/YR) | (KG/YR) | (KG/YR) | (KG/YR) | (KG/YR) | (KG/YR) | (KG/YR) | (KG/YR) | (KG/YR) |
| Urban 1 (Residential) | 60.00 | 42.50 | 42.00 | 236.99 | 33.31 | 22.42 | 90.31 | 0.00 | 0.00 | 0.00 | 527.53 |
| Urban 2 (Roads) | 18.60 | 27.33 | 0.00 | 29.62 | 4.16 | 2.80 | 11.29 | 0.00 | 0.00 | 0.00 | 93.81 |
| Urban 3 (Mixed Urban/Commercial) | 18.00 | 29.00 | 0.00 | 29.62 | 4.16 | 2.80 | 11.29 | 0.00 | 0.00 | 0.00 | 94.88 |
| Urban 4 (Industrial) | 0.00 | 0.00 | 0.00 | 117.50 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 117.50 |
| Urban 5 (Parks, Recreation Fields, Institutional) | 0.00 | 16.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 16.00 |
| Agric 1 (Cover Crop) | 0.00 | 0.00 | 0.00 | 1.91 | 30.75 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 32.66 |
| Agric 2 (Row Crop) | 0.00 | 0.00 | 0.00 | 0.00 | 40.50 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 40.50 |
| Agric 3 (Grazing) | 0.00 | 0.00 | 0.00 | 0.00 | 20.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 20.00 |
| Agric 4 (Feedlot) | 0.00 | 0.00 | 0.00 | 0.00 | 12.50 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 12.50 |
| Forest 1 (Upland) | 7.71 | 17.50 | 50.30 | 90.30 | 9.20 | 32.00 | 33.55 | 0.00 | 0.00 | 0.00 | 240.56 |
| Forest 2 (Wetland) | 0.00 | 0.25 | 0.00 | 14.46 | 0.00 | 0.00 | 1.91 | 0.00 | 0.00 | 0.00 | 16.61 |
| Open 1 (Wetland/Lake) | 1.23 | 0.28 | 1.00 | 0.05 | 0.00 | 0.03 | 7.10 | 0.00 | 0.00 | 0.00 | 9.69 |
| Open 2 (Meadow) | 1.00 | 0.63 | 0.00 | 5.12 | 0.03 | 0.00 | 0.10 | 0.00 | 0.00 | 0.00 | 6.89 |
| Open 3 (Excavation) | 0.06 | 0.05 | 0.00 | 1.14 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.24 |
| Other 1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Other 2 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Other 3 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Point Source #1 | 0.00 | 0.00 | 0.00 | 540.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 540.00 |
| Point Source #2 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Point Source #3 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | | | | | | | | | |
| TOTAL | 106.60 | 133.54 | 93.30 | 1066.71 | 154.61 | 60.06 | 155.54 | 0.00 | 0.00 | 0.00 | 1770.36 |

### Load Routing Pattern

The model must be told how to route all inputs of water, TP and TN before they reach the lake. Since attenuation in an upstream basin can affect inputs in an upstream basin that passes through the downstream basin, the model must be directed as to where to apply attenuation factors and additive effects. In the table below, each basin listed on the lines labeled on the left that passes through another basin labeled by column is denoted with a 1 in the column of the basin through which it passes. Otherwise, a 0 appears in each shaded cell. All basins pass through themselves, so the first line has a 1 in each cell. Basins 1 and 2 go direct to the lake, and so all other cells on the corresponding lines have 0 entries. Basin 3 passes through Basin 4 (see Figure 2), and so the line for Basin 3 has a 1 in the column for Basin 4. Likewise, Basins 5 and 6 pass through Basin 7, so the corresponding lines have a 1 entered in the column for Basin 7.

| ROUTING PATTERN | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | (Basin in left hand column passes through basin in column below if indicated by a 1) | | | | | | | | | |
| 1=YES 0=NO XXX=BLANK | BASIN 1 | BASIN 2 | BASIN 3 | BASIN 4 | BASIN 5 | BASIN 6 | BASIN 7 | BASIN 8 | BASIN 9 | BASIN 10 |
| | E. Direct | W. Direct | Upper T1 | Lower T1 | W. Upper T2 | E. Upper T2 | Lower T2 | | | |
| | (CU.M/YR) | (CU.M/YR) | (CU.M/YR) | (CU.M/YR) | (CU.M/YR) | (CU.M/YR) | (CU.M/YR) | (CU.M/YR) | (CU.M/YR) | (CU.M/YR) |
| INDIVIDUAL BASIN | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| BASIN 1 OUTPUT | XXX | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| BASIN 2 OUTPUT | 0 | XXX | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| BASIN 3 OUTPUT | 0 | 0 | XXX | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| BASIN 4 OUTPUT | 0 | 0 | 0 | XXX | 0 | 0 | 0 | 0 | 0 | 0 |
| BASIN 5 OUTPUT | 0 | 0 | 0 | 0 | XXX | 0 | 1 | 0 | 0 | 0 |
| BASIN 6 OUTPUT | 0 | 0 | 0 | 0 | 0 | XXX | 1 | 0 | 0 | 0 |
| BASIN 7 OUTPUT | 0 | 0 | 0 | 0 | 0 | 0 | XXX | 0 | 0 | 0 |
| BASIN 8 OUTPUT | 0 | 0 | 0 | 0 | 0 | 0 | 0 | XXX | 0 | 0 |
| BASIN 9 OUTPUT | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | XXX | 0 |
| BASIN 10 OUTPUT | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | XXX |

| CUMULATIVE DRAINAGE AREAS | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | (Total land area associated with routed water and nutrients) | | | | | | | | | |
| 1=YES 0=NO XXX=BLANK | BASIN 1 | BASIN 2 | BASIN 3 | BASIN 4 | BASIN 5 | BASIN 6 | BASIN 7 | BASIN 8 | BASIN 9 | BASIN 10 |
| | E. Direct | W. Direct | Upper T1 | Lower T1 | W. Upper T2 | E. Upper T2 | Lower T2 | | | |
| | (CU.M/YR) | (CU.M/YR) | (CU.M/YR) | (CU.M/YR) | (CU.M/YR) | (CU.M/YR) | (CU.M/YR) | (CU.M/YR) | (CU.M/YR) | (CU.M/YR) |
| INDIVIDUAL BASIN | 31.6 | 42.6 | 60.7 | 200.9 | 50.6 | 37.7 | 72.4 | 0.0 | 0.0 | 0.0 |
| BASIN 1 OUTPUT | XXX | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| BASIN 2 OUTPUT | 0.0 | XXX | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| BASIN 3 OUTPUT | 0.0 | 0.0 | XXX | 60.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| BASIN 4 OUTPUT | 0.0 | 0.0 | 0.0 | XXX | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| BASIN 5 OUTPUT | 0.0 | 0.0 | 0.0 | 0.0 | XXX | 0.0 | 50.6 | 0.0 | 0.0 | 0.0 |
| BASIN 6 OUTPUT | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | XXX | 37.7 | 0.0 | 0.0 | 0.0 |
| BASIN 7 OUTPUT | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | XXX | 0.0 | 0.0 | 0.0 |
| BASIN 8 OUTPUT | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | XXX | 0.0 | 0.0 |
| BASIN 9 OUTPUT | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | XXX | 0.0 |
| BASIN 10 OUTPUT | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | XXX |
| | | | | | | | | | | |
| TOTALS | 31.6 | 42.6 | 60.7 | 261.6 | 50.6 | 37.7 | 160.7 | 0.0 | 0.0 | 0.0 |

The model then combines the appropriate watershed areas as shown above, generating larger sub-watersheds that are used later to calculate overall export coefficients, comparative water yields, and related checks for model accuracy.

## Load Routing and Attenuation

With the loads calculated previously for each basin under wet and dry conditions and the routing of those loads specified, the model can then combine those loads and apply attenuation values chosen to reflect expected losses of water, TP or TN while the generated loads are on their way to the lake.

### Water

Water is attenuated mostly by evapotranspiration losses. Some depression storage is expected, seepage into the ground is possible, and wetlands can remove considerable water on the way to the lake. In general, a 5% loss is to be expected in nearly all cases, and greater losses are plausible with lower gradient or wetland dominated landscapes. In the example system, only the lower portion of Tributary 2 is expected to have more than a 5% loss, with a 15% loss linked to the wetland associated with this drainage area and tributary (see Figure 1).

| WATER ROUTING AND ATTENUATION | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | BASIN 1 | BASIN 2 | BASIN 3 | BASIN 4 | BASIN 5 | BASIN 6 | BASIN 7 | BASIN 8 | BASIN 9 | BASIN 10 |
| | E. Direct | W. Direct | Upper T1 | Lower T1 | W. Upper T2 | E. Upper T2 | Lower T2 | | | |
| SOURCE | (CU.M/YR) | (CU.M/YR) | (CU.M/YR) | (CU.M/YR) | (CU.M/YR) | (CU.M/YR) | (CU.M/YR) | (CU.M/YR) | (CU.M/YR) | (CU.M/YR) |
| INDIVIDUAL BASIN | 185594 | 247067 | 362153 | 1231497 | 321916 | 226145 | 421308 | 0 | 0 | 0 |
| BASIN 1 OUTPUT | XXX | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| BASIN 2 OUTPUT | 0 | XXX | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| BASIN 3 OUTPUT | 0 | 0 | XXX | 344045 | 0 | 0 | 0 | 0 | 0 | 0 |
| BASIN 4 OUTPUT | 0 | 0 | 0 | XXX | 0 | 0 | 0 | 0 | 0 | 0 |
| BASIN 5 OUTPUT | 0 | 0 | 0 | 0 | XXX | 0 | 305820 | 0 | 0 | 0 |
| BASIN 6 OUTPUT | 0 | 0 | 0 | 0 | 0 | XXX | 214838 | 0 | 0 | 0 |
| BASIN 7 OUTPUT | 0 | 0 | 0 | 0 | 0 | 0 | XXX | 0 | 0 | 0 |
| BASIN 8 OUTPUT | 0 | 0 | 0 | 0 | 0 | 0 | 0 | XXX | 0 | 0 |
| BASIN 9 OUTPUT | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | XXX | 0 |
| BASIN 10 OUTPUT | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | XXX |
| | | | | | | | | | | |
| CUMULATIVE TOTAL | 185594 | 247067 | 362153 | 1575542 | 321916 | 226145 | 941966 | 0 | 0 | 0 |
| BASIN ATTENUATION | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 | 0.85 | 1.00 | 1.00 | 1.00 |
| OUTPUT VOLUME | 176314 | 234714 | 344045 | 1496765 | 305820 | 214838 | 800671 | 0.0 | 0.0 | 0.0 |
| | | | | | | | | | | |
| Reality Check from Flow Data | | | | 1500000.0 | | | 800000.0 | | | |
| Calculated Flow/Measured Flow | #DIV/0! | #DIV/0! | #DIV/0! | 0.998 | #DIV/0! | #DIV/0! | 1.001 | #DIV/0! | #DIV/0! | #DIV/0! |
| | | | | | | | | | | |
| Reality Check from Areal Yield X Basin Area | 174638.7 | 235450.8 | 335258.2 | 1444750.2 | 279386.8 | 208035.3 | 887509.1 | 0.0 | 0.0 | 0.0 |
| Calculated Flow/Flow from Areal Yield | 1.010 | 0.997 | 1.026 | 1.036 | 1.095 | 1.033 | 0.902 | #DIV/0! | #DIV/0! | #DIV/0! |

The resulting output volume for each basin is calculated in the table below, and two reality check opportunities are provided. First any actual data can be added for direct comparison; average flows are available for only two points, the inlets of the two tributaries, but these are useful. In many cases no flow data may be available. The model therefore generates an estimate of the expected average flow as a function of all contributing upstream watershed area and the water yield provided near the top of the Calculations sheet (covered previously). While this flow estimate is approximate, it should not vary from the modeled flow by more than about 20% unless there are unusual circumstances.

In the example, the ratio of the calculated flow from the complete model generation and routing to the estimated yield from the contributing drainage area ranges from 0.902 to 1.095, suggesting fairly close agreement. As some ratios are lower than 1 and others are higher than 1, no model-wide adjustment is likely to bring the values into closer agreement. Slight changes in attenuation for each basin could be applied, but are not necessary when the values agree this closely.

### Phosphorus

The same approach applied to attenuation of water is applied to the phosphorus load, as shown in the table below. Here attenuation can range from 0 to 1.0, with the value shown representing the portion of the load that reaches the terminus of the basin. With natural or human enhanced removal processes, it is unusual for all of the load to pass through a basin, but it is also unusual for more than 60 to 70% of it to be removed. What value to pick depends on professional judgment regarding the nature of removal processes in each basin. Infiltration, filtration, detention and uptake will lower the attenuation value entered below, and knowledge of the literature on Best Management Practices is needed to make reliable judgments on attenuation values.

| LOAD ROUTING AND ATTENUATION: PHOSPHORUS | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | BASIN 1 | BASIN 2 | BASIN 3 | BASIN 4 | BASIN 5 | BASIN 6 | BASIN 7 | BASIN 8 | BASIN 9 | BASIN 10 |
| | E. Direct | W. Direct | Upper T1 | Lower T1 | W. Upper T2 | E. Upper T2 | Lower T2 | | | |
| | (KG/YR) | (KG/YR) | (KG/YR) | (KG/YR) | (KG/YR) | (KG/YR) | (KG/YR) | (KG/YR) | (KG/YR) | (KG/YR) |
| BASIN 1 INDIVIDUAL | 15.8 | 20.9 | 16.3 | 215.8 | 147.6 | 10.4 | 24.1 | 0.0 | 0.0 | 0.0 |
| BASIN 1 OUTPUT | XXX | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| BASIN 2 OUTPUT | 0.0 | XXX | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| BASIN 3 OUTPUT | 0.0 | 0.0 | XXX | 12.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| BASIN 4 OUTPUT | 0.0 | 0.0 | 0.0 | XXX | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| BASIN 5 OUTPUT | 0.0 | 0.0 | 0.0 | 0.0 | XXX | 0.0 | 118.1 | 0.0 | 0.0 | 0.0 |
| BASIN 6 OUTPUT | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | XXX | 7.8 | 0.0 | 0.0 | 0.0 |
| BASIN 7 OUTPUT | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | XXX | 0.0 | 0.0 | 0.0 |
| BASIN 8 OUTPUT | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | XXX | 0.0 | 0.0 |
| BASIN 9 OUTPUT | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | XXX | 0.0 |
| BASIN 10 OUTPUT | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | XXX |
| | | | | | | | | | | |
| CUMULATIVE TOTAL | 15.8 | 20.9 | 16.3 | 228.0 | 147.6 | 10.4 | 149.9 | 0.0 | 0.0 | 0.0 |
| BASIN ATTENUATION | 0.90 | 0.90 | 0.75 | 0.85 | 0.80 | 0.75 | 0.70 | 1.00 | 1.00 | 1.00 |
| OUTPUT LOAD | 14.2 | 18.8 | 12.2 | 193.8 | 118.1 | 7.8 | 104.9 | 0.0 | 0.0 | 0.0 |

In the example system, the direct drainage basins were assigned values of 0.90, representing a small amount of removal mainly by infiltration processes. Upper Tributary #1 has a small pond and was accorded a value of 0.75 (25% removal); a larger pond might have suggested a value closer to 0.5. Lower Tributary #1 has an assigned value of 0.85 based on channel processes that favor uptake and adsorption. West and East Upper Tributary #2 have value based on drainage basin features as evaluated in the field, while the wetland associated with Lower Tributary #2 garners it the lowest load pass-through at 0.7. A more extensive wetland with greater sheet flow might have earned a value near 0.5. Resulting output loads are then calculated.

### Nitrogen

The same process used with water and TP attenuation applies to TN, but attenuation of TN is rarely identical to that for TP. Nitrogen moves more readily through soil, and while transformations occur in the stream, losses due to denitrification require slower flows and low oxygen levels not commonly encountered in steeper, rockier channels. However, losses from uptake and possibly denitrification are possible in wetland areas, such as that associated with Lower Tributary #2. Accordingly, attenuation values are assigned as shown in the table below, with generally lower losses for TN than for TP. As with TP attenuation, choosing appropriate values does require some professional judgment.

| LOAD ROUTING AND ATTENUATION: NITROGEN | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | BASIN 1 | BASIN 2 | BASIN 3 | BASIN 4 | BASIN 5 | BASIN 6 | BASIN 7 | BASIN 8 | BASIN 9 | BASIN 10 |
| | E. Direct | W. Direct | Upper T1 | Lower T1 | W. Upper T2 | E. Upper T2 | Lower T2 | | | |
| | (KG/YR) | (KG/YR) | (KG/YR) | (KG/YR) | (KG/YR) | (KG/YR) | (KG/YR) | (KG/YR) | (KG/YR) | (KG/YR) |
| BASIN 1 INDIVIDUAL | 246.5 | 315.6 | 290.1 | 1863.3 | 1929.8 | 182.6 | 416.6 | 0.0 | 0.0 | 0.0 |
| BASIN 1 OUTPUT | XXX | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| BASIN 2 OUTPUT | 0.0 | XXX | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| BASIN 3 OUTPUT | 0.0 | 0.0 | XXX | 232.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| BASIN 4 OUTPUT | 0.0 | 0.0 | 0.0 | XXX | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| BASIN 5 OUTPUT | 0.0 | 0.0 | 0.0 | 0.0 | XXX | 0.0 | 1543.8 | 0.0 | 0.0 | 0.0 |
| BASIN 6 OUTPUT | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | XXX | 146.0 | 0.0 | 0.0 | 0.0 |
| BASIN 7 OUTPUT | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | XXX | 0.0 | 0.0 | 0.0 |
| BASIN 8 OUTPUT | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | XXX | 0.0 | 0.0 |
| BASIN 9 OUTPUT | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | XXX | 0.0 |
| BASIN 10 OUTPUT | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | XXX |
| | | | | | | | | | | |
| CUMULATIVE TOTAL | 246.5 | 315.6 | 290.1 | 2095.4 | 1929.8 | 182.6 | 2106.4 | 0.0 | 0.0 | 0.0 |
| BASIN ATTENUATION | 0.95 | 0.95 | 0.80 | 0.90 | 0.80 | 0.80 | 0.75 | 1.00 | 1.00 | 1.00 |
| OUTPUT LOAD | 234.2 | 299.8 | 232.1 | 1885.8 | 1543.8 | 146.0 | 1579.8 | 0.0 | 0.0 | 0.0 |

## Load and Concentration Summary

### Water

Water loads were handled to the extent necessary in the previous loading calculations, and are used in this section only to allow calculation of expected TP and TN concentrations, facilitating reality checks with actual data.

### Phosphorus

Using the calculated load of TP for each basin and the corresponding water volume, an average expected concentration can be derived, as shown in the table below. Where sampling provides actual data, values can be compared to determine how well the model represents known reality. Sufficient sampling is needed to make the reality check values reliable; it is not appropriate to assume that either the data or the model is necessarily accurate when the values disagree. However, with enough data to adequately characterize the concentrations observed in the stream, the model can be adjusted to produce a better match. Estimated and actual concentrations are used to generate a ratio for easy comparison.

The TP loads previously calculated represent the load passing through each basin, but do not represent what reaches the lake, as not all basins are terminal input sources. The model must be told which basins actually drain directly to the lake, and for which the exiting load is part of the total load to the lake.

| LOAD AND CONCENTRATION SUMMARY: PHOSPHORUS | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | BASIN 1 | BASIN 2 | BASIN 3 | BASIN 4 | BASIN 5 | BASIN 6 | BASIN 7 | BASIN 8 | BASIN 9 | BASIN 10 | |
| | E. Direct | W. Direct | Upper T1 | Lower T1 | W. Upper T2 | E. Upper T2 | Lower T2 | | | | |
| OUTPUT (CU.M/YR) | 176314 | 234714 | 344045 | 1496765 | 305820 | 214838 | 800671 | 0 | 0 | 0 | |
| OUTPUT (KG/YR) | 14.2 | 18.8 | 12.2 | 193.8 | 118.1 | 7.8 | 104.9 | 0.0 | 0.0 | 0.0 | |
| OUTPUT (MG/L) | 0.081 | 0.080 | 0.035 | 0.129 | 0.386 | 0.036 | 0.131 | #DIV/0! | #DIV/0! | #DIV/0! | |
| REALITY CHECK CONC. (FROM DATA) | 0.078 | 0.076 | 0.040 | 0.150 | 0.325 | 0.035 | 0.125 | | | | |
| CALCULATED CONC./MEASURED CONC. | 1.035 | 1.056 | 0.886 | 0.863 | 1.188 | 1.038 | 1.049 | #DIV/0! | #DIV/0! | #DIV/0! | |
| BASIN EXPORT COEFFICIENT | 0.45 | 0.44 | 0.20 | 0.74 | 2.33 | 0.21 | 0.65 | #DIV/0! | #DIV/0! | #DIV/0! | |
| | | | | | | | | | | | |
| TERMINAL DISCHARGE? | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | |
| (1=YES 2=NO) | | | | | | | | | | | |
| | | | | | | | | | | | |
| LOAD TO RESOURCE | | | | | | | | | | | TOTAL |
| WATER (CU.M/YR) | 176314 | 234714 | 0 | 1496765 | 0 | 0 | 800671 | 0 | 0 | 0 | 2708464 |
| PHOSPHORUS (KG/YR) | 14.2 | 18.8 | 0.0 | 193.8 | 0.0 | 0.0 | 104.9 | 0.0 | 0.0 | 0.0 | 331.8 |
| PHOSPHORUS (MG/L) | 0.081 | 0.080 | 0.000 | 0.129 | 0.000 | 0.000 | 0.131 | #DIV/0! | #DIV/0! | #DIV/0! | 0.123 |

For the example system, the ratio of the calculated concentration to average actual values derived from substantial sampling (typically on the order of 10 or more samples representing the range of dry to wet conditions) ranges from 0.886 to 1.188, or from 11% low to 19% high, within a generally acceptable range of +20%. This is not a strict threshold, especially with lower TP concentrations where detection limits and intervals of expression for methods can produce higher percent deviation with very small absolute differences. Yet in general, <20% difference between observed and expected watershed basin output values is considered reasonable for a model at this level of sophistication.

That some values are higher than expected and others lower suggests that now model-wide adjustment will improve agreement (such as an export coefficient change), but attenuation values for individual basins could be adjusted if there is justification.

For the example system, Basins 1, 2, 4 and 7 contribute directly to the lake, and are so denoted by a 1 in their respective columns on the line for terminal discharge. These loads will be summed to derive a watershed load of TP to the lake.

**Nitrogen**

The model process followed for TN is identical to that applied to TP loads from basins. For TN in the example system, comparison of expected vs. observed values yields a range of ratios from 0.929 to 1.188, representing 7% low to 19% high. Only one out of seven values is lower than 1, so perhaps some adjustment of the TN export coefficients is in order, but most individual basin values are within 8% of each other, so without clear justification, the judgment exercised in the original choices for export coefficients and attenuation is not generally overridden. The same basins denoted as terminal discharges for TP are so noted for TN, allowing calculation of the total watershed load of TN to the lake.

| LOAD AND CONCENTRATION SUMMARY: NITROGEN | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | BASIN 1 | BASIN 2 | BASIN 3 | BASIN 4 | BASIN 5 | BASIN 6 | BASIN 7 | BASIN 8 | BASIN 9 | BASIN 10 | |
| | E. Direct | W. Direct | Upper T1 | Lower T1 | W. Upper T2 | E. Upper T2 | Lower T2 | | | | |
| OUTPUT (CU.M/YR) | 176314 | 234714 | 344045 | 1496765 | 305820 | 214838 | 800671 | 0 | 0 | 0 | |
| OUTPUT (KG/YR) | 234.2 | 299.8 | 232.1 | 1885.8 | 1543.8 | 146.0 | 1579.8 | 0.0 | 0.0 | 0.0 | |
| OUTPUT MG/L | 1.328 | 1.277 | 0.675 | 1.260 | 5.048 | 0.680 | 1.973 | #DIV/0! | #DIV/0! | #DIV/0! | |
| REALITY CHECK CONC. (FROM DATA) | 1.430 | 1.240 | 0.650 | 1.180 | 4.250 | 0.650 | 1.830 | | | | |
| CALCULATED CONC./MEASURED CONC. | 0.929 | 1.030 | 1.038 | 1.068 | 1.188 | 1.046 | 1.078 | #DIV/0! | #DIV/0! | #DIV/0! | |
| BASIN EXPORT COEFFICIENT | 7.41 | 7.03 | 3.82 | 7.21 | 30.52 | 3.88 | 9.83 | #DIV/0! | #DIV/0! | #DIV/0! | |
| | | | | | | | | | | | |
| TERMINAL DISCHARGE? | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | |
| (1=YES 2=NO) | | | | | | | | | | | |
| | | | | | | | | | | | |
| LOAD TO RESOURCE | | | | | | | | | | | TOTAL |
| WATER (CU.M/YR) | 176314 | 234714 | 0 | 1496765 | 0 | 0 | 800671 | 0 | 0 | 0 | 2708464 |
| NITROGEN (KG/YR) | 234.2 | 299.8 | 0.0 | 1885.8 | 0.0 | 0.0 | 1579.8 | 0.0 | 0.0 | 0.0 | 3999.7 |
| NITROGEN (MG/L) | 1.328 | 1.277 | 0.000 | 1.260 | 0.000 | 0.000 | 1.973 | #DIV/0! | #DIV/0! | #DIV/0! | 1.477 |

**Grand Totals**

The final portion of the Calculation sheet is a summary of all loads to the lake and a grand total load with associated concentrations for TP and TN, as shown below. The breakdown of sources is provided for later consideration in both overall target setting and in consideration of BMPs. For the example system, the watershed load is clearly dominant, and would need to be addressed if substantial reductions in loading were considered necessary. The loads of water, TP and TN are then transferred automatically to the Prediction sheet to facilitate estimation of in-lake concentrations of TP, TN and Chl and a value for SDT. The derived overall input concentration for TP is also transferred; the in-lake predictive models for TN do not require that overall input concentration, but the comparison of TP and TN input levels can be insightful when considering what types of algae are likely to dominate the lake phytoplankton.

| LOAD SUMMARY | | | |
|---|---|---|---|
| DIRECT LOADS TO LAKE | P (KG/YR) | N (KG/YR) | WATER (CU.M/YR) |
| ATMOSPHERIC | 8.0 | 260.0 | 484000 |
| INTERNAL | 40.0 | 100.0 | 0 |
| WATERFOWL | 10.0 | 47.5 | 0 |
| SEPTIC SYSTEM | 31.8 | 517.0 | 31250 |
| WATERSHED LOAD | 331.7 | 3998.4 | 2707372 |
| | | | |
| TOTAL LOAD TO LAKE | 421.5 | 4922.9 | 3222622 |
| (Watershed + direct loads) | | | |
| TOTAL INPUT CONC. (MG/L) | 0.131 | 1.528 | |

**Water Quality Predictions**

Prediction of TP, TN, Chl and SDT is based on empirical equations from the literature, nearly all pertaining to North American systems. Only a few additional pieces of information are needed to run the model; most of the needed input data are automatically transferred from the Calculations sheet. As shown below, only the concentration of TP leaving the lake and the lake volume must be entered on the Prediction sheet. If the outflow TP level is not known, the in-lake surface concentration is normally used. If the volume is not specifically known, an average depth can be multiplied by the lake area to derive an input volume, which will then recalculate the average depth one cell below. The nature of the TN prediction models does not require any TN concentration input.

| IN-LAKE MODELS FOR PREDICTING CONCENTRATIONS: Current Conditions | | | | | |
|---|---|---|---|---|---|
| ***THE TERMS*** | | | | | |
| | ***PHOSPHORUS*** | | | | |
| | | | | | |
| **SYMBOL** | **PARAMETER** | **UNITS** | **DERIVATION** | **VALUE** | |
| TP | Lake Total Phosphorus Conc. | ppb | From in-lake models | To Be Predicted | |
| KG | Phosphorus Load to Lake | kg/yr | From export model | 422 | |
| L | Phosphorus Load to Lake | g P/m2/yr | KG*1000/A | 1.054 | |
| TPin | Influent (Inflow) Total Phosphorus | ppb | From export model | 131 | |
| TPout | Effluent (Outlet) Total Phosphorus | ppb | From data, if available | 75 | Enter Value (TP out) |
| I | Inflow | m3/yr | From export model | 3222622 | |
| A | Lake Area | m2 | From data | 400000 | |
| V | Lake Volume | m3 | From data | 1625300 | Enter Value (V) |
| Z | Mean Depth | m | Volume/area | 4.063 | |
| F | Flushing Rate | flushings/yr | Inflow/volume | 1.983 | |
| S | Suspended Fraction | no units | Effluent TP/Influent TP | 0.573 | |
| Qs | Areal Water Load | m/yr | Z(F) | 8.057 | |
| Vs | Settling Velocity | m | Z(S) | 2.330 | |
| Rp | Retention Coefficient (settling rate) | no units | ((Vs+13.2)/2)/(((Vs+13.2)/2)+Qs) | 0.491 | |
| Rlm | Retention Coefficient (flushing rate) | no units | 1/(1+F^0.5) | 0.415 | |
| | | | | | |
| | ***NITROGEN*** | | | | |
| | | | | | |
| **SYMBOL** | **PARAMETER** | **UNITS** | **DERIVATION** | **VALUE** | |
| TN | Lake Total Nitrogen Conc. | ppb | From in-lake models | To Be Predicted | |
| KG | Nitrogen Load to Lake | kg/yr | From export model | 4923 | |
| L1 | Nitrogen Load to Lake | g N/m2/yr | KG*1000/A | 12.31 | |
| L2 | Nitrogen Load to Lake | mg N/m2/yr | KG*1000000/A | 12307 | |
| C1 | Coefficient of Attenuation, from F | fraction/yr | 2.7183^(0.5541(ln(F))-0.367) | 1.01 | |
| C2 | Coefficient of Attenuation, from L | fraction/yr | 2.7183^(0.71(ln(L2))-6.426) | 1.30 | |
| C3 | Coefficient of Attenuation, from L/Z | fraction/yr | 2.7183^(0.594(ln(L2/Z))-4.144) | 1.85 | |

### Phosphorus Concentration

TP concentration is predicted from the equations shown below. The mass balance calculation is simply the TP load divided by the water load, and assumes no losses to settling within the lake. Virtually all lakes have settling losses, but the other equations derive that settling coefficient in different ways, providing a range of possible TP concentration values. Where there is knowledge of the components of the settling calculations, a model might be selected as most representative or models might be eliminated as inapplicable, but otherwise the average of the five empirical models (excluding the mass balance calculation) is accepted as the predicted TP value for the lake.

| ***THE MODELS*** | | | | |
|---|---|---|---|---|
| | ***PHOSPHORUS*** | **PRED.** | **PERMIS.** | **CRITICAL** |
| | | **CONC.** | **CONC.** | **CONC.** |
| **NAME** | **FORMULA** | **(ppb)** | **(ppb)** | **(ppb)** |
| Mass Balance | TP=L/(Z(F))*1000 | 131 | | |
| (Maximum Conc.) | | | | |
| Kirchner-Dillon 1975 | TP=L(1-Rp)/(Z(F))*1000 | 67 | 18 | 36 |
| (K-D) | | | | |
| Vollenweider 1975 | TP=L/(Z(S+F))*1000 | 101 | 27 | 55 |
| (V) | | | | |
| Larsen-Mercier 1976 | TP=L(1-Rlm)/(Z(F))*1000 | 76 | 21 | 41 |
| (L-M) | | | | |
| Jones-Bachmann 1976 | TP=0.84(L)/(Z(0.65+F))*1000 | 83 | 22 | 45 |
| (J-B) | | | | |
| Reckhow General (1977) | TP=L/(11.6+1.2(Z(F)))*1000 | 50 | 13 | 27 |
| (Rg) | | | | |
| | | | | |
| Average of Model Values | | 75 | 20 | 41 |
| (without mass balance) | | | | |
| Measured Value | | 75 | | |
| (mean, median, other) | | | | |
| | | | | |
| From Vollenweider 1968 | | | | |
| Permissible Load (g/m2/yr) | Lp=10^(0.501503(log(Z(F)))-1.0018) | 0.28 | | |
| Critical Load (g/m2/yr) | Lc=2(Cp) | 0.57 | | |

The predicted in-lake TP concentration can be compared to actual data (an average value is entered in the shaded cell as a reality check) and to calculation of the permissible and critical concentrations as derived from Vollenweider's 1968 work. For the example lake, the predicted TP level of 75 ug/L is an exact match for the measured value of 75 ug/L, but both are well above the critical concentration.

The permissible concentration is the value above which algal blooms are to be expected on a potentially unacceptable frequency, while the critical concentration is the level above which unacceptable algal growths are to be expected, barring extreme flushing, toxic events, or light limitation from suspended sediment.

Use of the range of values derived from these empirical equations provides some sense for the uncertainty in the analysis. Changing input loads, lake volume, or other key variables allows for sensitivity analysis.

**Nitrogen Concentration**

Prediction of TN is based on three separate empirical equations from the same work, each calculating settling losses differently. A mass balance equation is applied as well, as with the prediction of TP. An actual mean value is normally entered in the shaded cell as a reality check. For the example system, the actual mean TN value is within the range of predicted values, but is about 5.6% lower than the average of predicted values. One might consider adjusting export coefficients or attenuation rates in the Calculations sheet, to bring these values closer together, but the discrepancy is relatively minor.

| | NITROGEN | |
|---|---|---|
| | | |
| Mass Balance | TN=L/(Z(F))*1000 | 1528 |
| (Maximum Conc.) | | |
| | | |
| Bachmann 1980 | TN=L/(Z(C1+F))*1000 | 1011 |
| Bachmann 1980 | TN=L/(Z(C2+F))*1000 | 923 |
| Bachmann 1980 | TN=L/(Z(C3+F))*1000 | 789 |
| | | |
| Average of Model Values | | 908 |
| (without mass balance) | | |
| Measured Value | | 860 |
| (mean, median, other) | | |

**Chlorophyll Concentration, Water Clarity and Bloom Probability**

Once an average in-lake TP concentration has been established, the Predictions sheet derives corresponding Chl and SDT values, as shown below. Five different equations are used to derive a predicted Chl value, and an average is derived. Peak Chl is estimated with three equations, with an average generated. Average and maximum expected SDT are estimated as well. Bloom frequency is based on the relationship of mean Chl to other threshold levels from other studies, and the portion of time that Chl is expected to exceed 10, 15, 20, 30 and 40 ug/L is derived.

A set of shaded cells are provided for entry of known measured values for comparison. For the example lake, the average and peak Chl levels predicted from the model are slightly higher than actual measured values, while the average and maximum SDT from the model are slightly lower than observed values, consistent with the Chl results. Agreement is generally high, however, with differences between 10 and 20%. There were not enough data to construct a dependable actual distribution of Chl over the range of thresholds provided for the example lake.

There are other factors besides nutrients that can strongly affect the standing crop of algae and resulting Chl levels, including low light from suspended sediment, grazing by zooplankton, presence of heterotrophic algae, and flushing effects from high flows. Consequently, close agreement between predicted and actual Chl will be harder to achieve than for predicted and actual TP. Knowledge of those other potentially important influences can help determine if model calibration is off, or if closer agreement is not rationally achievable.

| *PREDICTED CHL AND WATER CLARITY* | | | |
|---|---|---|---|
| | | | |
| | | | |
| **MODEL** | **Value** | **Mean** | **Measured** |
| | | | |
| **Mean Chlorophyll (ug/L)** | | | |
| Carlson 1977 | 45.9 | | |
| Dillon and Rigler 1974 | 38.4 | | |
| Jones and Bachmann 1976 | 44.7 | | |
| Oglesby and Schaffner 1978 | 40.4 | | |
| Modified Vollenweider 1982 | 35.5 | 41.0 | 37.5 |
| **Peak Chlorophyll (ug/L)** | | | |
| Modified Vollenweider (TP) 1982 | 119.7 | | |
| Vollenweider (CHL) 1982 | 133.1 | | |
| Modified Jones, Rast and Lee 1979 | 139.5 | 130.8 | 118.1 |
| **Secchi Transparency (M)** | | | |
| Oglesby and Schaffner 1978 **(Avg)** | 0.8 | | 1.0 |
| Modified Vollenweider 1982 **(Max)** | 2.9 | | 3.1 |
| | | | |
| **Bloom Probability** | | | |
| Probability of Chl >10 ug/L **(% of time)** | 99.5% | | |
| Probability of Chl >15 ug/L **(% of time)** | 96.1% | | |
| Probability of Chl >20 ug/L **(% of time)** | 88.2% | | |
| Probability of Chl >30 ug/L **(% of time)** | 64.6% | | |
| Probability of Chl >40 ug/L **(% of time)** | 42.0% | | |

## Evaluating Initial Results

LLRM is not meant to be a “black box” model. One can look at any cell and discern which steps are most important to final results in any give case. Several quality control processes are recommended in each application.

### Checking Values

Many numerical entries must be made to run LLRM. Be sure to double check the values entered. Simple entry errors can cause major discrepancies between predictions and reality. Where an export coefficient is large, most notably with Agric4, feedlot area, it is essential that the land use actually associated with that activity be accurately assessed and entered.

### Following Loads

For any individually identified load that represents a substantial portion of the total load (certainly >25%, perhaps as small a portion as 10%), it is appropriate to follow that load from generation through delivery to the lake, observing the losses and transformations along the way. Sometimes the path will be very short, and sometimes there may be multiple points where attenuation is applied. Consider dry vs. wet weather inputs and determine if the ratio is reasonable in light of actual data or field observations. Are calculated concentrations at points of measurement consistent with the actual measurements? Are watershed processes being adequately represented? One limitation of the model involves application of attenuation for all loads within a defined basin; loads may enter at the distal or proximal ends of the basin, and attenuation may not apply equally to all sources. Where loading and attenuation are not being properly represented, consider subdividing the basin to work with drainages of the most meaningful sizes.

### Reality Checks

LLRM can be run with minimal actual water quality data, but to gain confidence in the predictions it is necessary to compare results with sufficient amounts of actual data for key points in the modeled system. Ideally, water quality will be tested at all identified nodes, including the output points for all basins, any point source discharges, any direct discharge pipes to the lake, and in the lake itself. Wet and dry weather sampling should be conducted. Flow values are highly desirable, but without a longer term record, considerable uncertainty will remain; variability in flow is often extreme, necessitating large data sets to get representative statistical representation. Where there are multiple measurement points, compare not just how close predicted values are to observed values, but the pattern. Are observed values consistently over- or underpredicted? A rough threshold of $\pm$20% is recommended as a starting point, with a mix of values in the + or – categories.

**Sensitivity Testing**
The sensitivity of LLRM can be evaluated by altering individual features and observing the effect on results. For any variable for which the value is rather uncertain, enter the maximum value conceivable, and record model results. Then repeat the process with the minimum plausible value, and compare to ascertain how much variation can be induced by error in that variable. Which variables seem to have the greatest impact on results? Those variables should receive the most attention in reality checking, ground truthing, and future monitoring, and would also be the most likely candidates for adjustment in model calibration, unless the initially entered values are very certain.

For example, the runoff coefficients for TP from the various land uses were set below the median literature values, based on knowledge of loads for some drainage areas from actual data for flow and concentration. However, it is possible that the actual load generated from various land uses is higher than initially assumed, and it is the attenuation that should be adjusted to achieve a predicted in-lake concentration that matches actual data. If the median TP export for runoff is entered into the Calculations sheet, substituting the unshaded values for the shaded values in the table below, the resulting in-lake TP prediction is 89 ug/L, much higher than the 75 ug/L from real data.

| LAND USE | Original P Export Coefficient (kg/ha/yr) | New P Export Coefficient (kg/ha/yr) |
|---|---|---|
| Urban 1 (Residential) | 0.65 | 1.10 |
| Urban 2 (Roads) | 0.75 | 1.10 |
| Urban 3 (Mixed Urban/Commercial) | 0.80 | 1.10 |
| Urban 4 (Industrial) | 0.70 | 1.10 |
| Urban 5 (Parks, Recreation Fields, Institutional) | 0.80 | 1.10 |
| Agric 1 (Cover Crop) | 0.80 | 0.80 |
| Agric 2 (Row Crop) | 1.00 | 2.20 |
| Agric 3 (Grazing) | 0.40 | 0.80 |
| Agric 4 (Feedlot) | 224.00 | 224.00 |
| Forest 1 (Upland) | 0.20 | 0.20 |
| Forest 2 (Wetland) | 0.10 | 0.20 |
| Open 1 (Wetland/Lake) | 0.10 | 0.20 |
| Open 2 (Meadow) | 0.10 | 0.20 |
| Open 3 (Excavation) | 0.80 | 0.80 |
| Other 1 | 0.20 | 0.20 |
| Other 2 | 1.10 | 1.10 |
| Other 3 | 2.20 | 2.20 |

To get a closer match for the known in-lake value, attenuation would have to be adjusted (reduction in the portion of the generated load that reaches the lake) by about 0.1 units (10%), as shown below. This would result in a predicted in-lake TP concentration of 77 ug/L, not far above the measured 75 ug/L. It is apparent that choice of export coefficients is fairly important, but that error in those choices can be compensated by adjustments in attenuation that are not too extreme to be believed. Yet those choices will affect the results of management scenario testing, and should be made carefully. The intent is to properly represent watershed processes, both loading and attenuation, not just the product of the two.

| | BASIN 1 E. Direct | BASIN 2 W. Direct | BASIN 3 Upper T1 | BASIN 4 Lower T1 | BASIN 5 W. Upper T2 | BASIN 6 E. Upper T2 | BASIN 7 Lower T2 |
|---|---|---|---|---|---|---|---|
| ORIGINAL BASIN ATTENUATION | 0.90 | 0.90 | 0.75 | 0.85 | 0.80 | 0.75 | 0.70 |
| NEW BASIN ATTENUATION | 0.80 | 0.80 | 0.65 | 0.75 | 0.70 | 0.65 | 0.60 |

Aside from changes in all export coefficients, one might consider the impact of changing a single value. As that value applies to all areas given for the corresponding land use, its impact will be proportional to the magnitude of that area relative to other land uses. A change in forested land use exports may be very influential if most of the watershed is forested. A much larger change would be necessary to cause similar impact for a land use that represents a small portion of the watershed.

**Model Calibration**

Actual adjustment of LLRM to get predicted results in reasonable agreement with actual data can be achieved by altering any of the input data. The key to proper calibration is to change values that have some uncertainty, and to change them in a way that makes sense in light of knowledge of the target watershed and lake. One would not change entered land use areas believed to be correct just to get the predictions to match actual data. Rather, one would adjust the export coefficients for land uses within the plausible range (see Reference Variables sheet), and in accordance with values that could be derived for selected drainage areas (within the target system or nearby) from actual data. Or one could adjust attenuation, determining that a detention area, wetland, or other landscape feature had somewhat greater or lesser attenuation capacity that initially estimated. Justification for all changes should be provided; model adjustment should be transparent and amenable to scrutiny.

For the example system, it may be appropriate to adjust either TN export coefficients or attenuation to get the average of the three empirical equation results for TN (see Predictions sheet) to match the observed average more closely. In the example, a predicted TN concentration of 908 ug/L was derived, while the average of quite a few in-lake samples was 860 ug/L. With a difference of <6%, this is not a major issue, but since all but one of the individual basin predictions for TN concentration were also overpredictions, adjustment can be justified.

If all the TN export coefficients in the Calculations sheet are reduced by 10%, an entirely plausible situation, the new TN prediction for the lake becomes 861 ug/L, a very close match for the observed 860 ug/L. Export coefficients were not changed selectively by land use; all were simply adjusted down a small amount, well within the range of possible variation in this system. Alternatively, if the TN attenuation coefficient for each basin is reduced in the Calculations sheet by 0.05 (representing 5% more loss of TN on the way to the lake), the new predicted in-lake TN concentration becomes 842 ug/L, not far below the observed 860 ug/L. Attenuation in each basin was adjusted the same way, showing no bias. Either of these adjustments (export coefficients or attenuation values) would be reasonable within the constraints of the model and knowledge of the system.

The only way to change the export coefficient for land use in a single basin is to split off that land use into one of the “Other” categories and have it appear in only the basins where a different export coefficient is justified. This is hardly ever done, and justification should involve supporting data. Likewise, if one basin had a particularly large load and a feature that might affect that load, one might justify changing the attenuation for just that one basin, but justification should be strong to interject this level of individual basin bias.

**Model Verification**

Proper verification of models involves calibration with one set of data, followed by running the model with different input data leading to different results, with data to verify that those results are appropriate. Where data exist for conditions in a different time period that led to different in-lake conditions, such verification is possible with LLRM, but such opportunities tend to be rare. If the lake level was raised by dam modification, and in-lake data are available for before and after the pool rise, a simple change in the lake volume (entered in the Predictions sheet) can simulate this and allow verification. If in-lake data exist from a time before there was much development in the watershed, this could also allow verification by changing the land use and comparing results to historic TP and TN levels in the lake. However, small changes in watershed land use are not likely to yield sufficiently large changes in in-lake conditions to be detectable with this model. Additionally, as LLRM is a steady state model, testing conditions in one year with wetter conditions against another year with drier conditions, with no change in land use, is really not a valid approach.

Model verification is a function of data availability for at least two periods of multiple years in duration with different conditions that can be represented by the model. Where available, use of these data to verify model performance is strongly advised. If predictions under the second set of conditions do not reasonably match the available data, adjustments in export coefficients, attenuation, or other features of the model may be needed. Understanding why conditions are not being properly represented is an important aspect of modeling, even when it is not possible to bring the model into complete agreement with available data.

**Scenario Testing**

LLRM is meant to be useful for evaluating possible consequences of land use conversions, changes in discharges, various management options, and related alterations of the watershed or lake. The primary purpose of this model is to allow the user to project possible consequences of actions and aid management and policy decision processes. Testing a conceived scenario involves changing appropriate input data and observing the results. Common scenario testing includes determining the likely “original” or “pre-settlement” condition of the lake, termed “Background Condition” here, and forecasting the benefit from possible Best Management Practices (BMPs).

**Background Conditions**

Simulation of Background Conditions is most often accomplished by changing all developed land uses to forest, wetland or water, whichever is most appropriate based on old land use maps or other sources of knowledge about watershed features prior to development of roads, towns, industry, and related human features. Default export coefficients for undeveloped land use types are virtually the same, so the distinction is not critical if records are sparse.

For the example system, all developed land uses were converted to forested upland, although it is entirely possible that some wetlands were filled for development before regulations to protect wetlands were promulgated, and some may even have been filled more recently. The resulting land use table, shown below, replaces that in the original model representing current conditions. The watershed area is the same, although in some cases diversions may change this aspect as well. Many lakes have been created by human action, such that setting all land uses to an undeveloped state would correspond to not having a lake present, but the assumption applied here is that the user is interested in the condition of the lake as it currently exists, but in the absence of human influences.

**BASIN AREAS**

| LAND USE | BASIN 1 E. Direct AREA (HA) | BASIN 2 W. Direct AREA (HA) | BASIN 3 Upper T1 AREA (HA) | BASIN 4 Lower T1 AREA (HA) | BASIN 5 W. Upper T2 AREA (HA) | BASIN 6 E. Upper T2 AREA (HA) | BASIN 7 Lower T2 AREA (HA) | BASIN 8 AREA (HA) | BASIN 9 AREA (HA) | BASIN 10 AREA (HA) | TOTAL AREA (HA) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Urban 1 (Residential) | | | | | | | | | | | 0.0 |
| Urban 2 (Roads) | | | | | | | | | | | 0.0 |
| Urban 3 (Mixed Urban/Commercial) | | | | | | | | | | | 0.0 |
| Urban 4 (Industrial) | | | | | | | | | | | 0.0 |
| Urban 5 (Parks, Recreation Fields, Institutional) | | | | | | | | | | | 0.0 |
| Agric 1 (Cover Crop) | | | | | | | | | | | 0.0 |
| Agric 2 (Row Crop) | | | | | | | | | | | 0.0 |
| Agric 3 (Grazing) | | | | | | | | | | | 0.0 |
| Agric 4 (Feedlot) | | | | | | | | | | | 0.0 |
| Forest 1 (Upland) | 27.1 | 40.6 | 60.7 | 176.0 | 50.5 | 37.6 | 56.2 | | | | 448.7 |
| Forest 2 (Wetland) | 0.0 | 0.2 | 0.0 | 14.5 | 0.0 | 0.0 | 1.9 | | | | 16.6 |
| Open 1 (Wetland/Lake) | 2.5 | 0.6 | 0.0 | 0.1 | 0.0 | 0.1 | 14.2 | | | | 17.5 |
| Open 2 (Meadow) | 2.0 | 1.3 | 0.0 | 10.2 | 0.1 | 0.0 | 0.2 | | | | 13.8 |
| Open 3 (Excavation) | | | | | | | | | | | 0.0 |
| Other 1 | | | | | | | | | | | 0.0 |
| Other 2 | | | | | | | | | | | 0.0 |
| Other 3 | | | | | | | | | | | 0.0 |
| TOTAL | 31.6 | 42.7 | 60.7 | 200.8 | 50.6 | 37.7 | 72.5 | 0 | 0 | | 496.6 |

Also altered in this example, but not shown explicitly here, are the internal load (reduced to typical background levels of 0.5 mg TP/m2/d and 2.0 mg TN/m2/d), point source (removed), septic system inputs (removed), and attenuation of TP and TN (values in cells lowered by10%, representing lesser transport to the lake through the natural landscape).

Resulting in-lake conditions, as indicated in the column of the table below labeled “Background Conditions,” include a TP concentration of 16 ug/L and a TN level of 366 ug/L. Average Chl is predicted at 5.7 ug/L, leading to a mean SDT of 2.7 m. Bloom frequency is expected to be 8.6% for Chl >10 ug/L and 1.5% for Chl >15 ug/L, with values >20 ug/L very rare. While the example lake appears to have never had extremely high water clarity, it was probably much more attractive and useable than it is now, based on comparison with current conditions in the table. If this lake was in an ecoregion with a target TP level of <16 ug/L, it is expected that meeting that limit would be very difficult, given apparent natural influences.

| **SUMMARY TABLE FOR SCENARIO TESTING** | Existing Conditions | | Background Conditions | Complete Build-out | WWTF Enhanced | Feasible BMPs |
|---|---|---|---|---|---|---|
| | Calibrated Model Value | Actual Data | Model Value | Model Value | Model Value | Model Value |
| Phosphorus (ppb) | 75 | 75 | 16 | 83 | 49 | 24 |
| Nitrogen (ppb) | 861 | 860 | 366 | 965 | 745 | 540 |
| Mean Chlorophyll (ug/L) | 40.7 | 37.5 | 5.7 | 46.7 | 23.3 | 9.3 |
| Peak Chlorophyll (ug/L) | 130.0 | 118.1 | 20.1 | 148.5 | 76.1 | 31.6 |
| Mean Secchi (m) | 0.8 | 1.0 | 2.7 | 0.8 | 1.2 | 2.0 |
| Peak Secchi (m) | 2.9 | 3.1 | 4.5 | 2.8 | 3.3 | 4.0 |
| | | | | | | |
| Bloom Probability | | | | | | |
| Probability of Chl >10 ug/L | 99.5% | | 8.6% | 99.8% | 92.6% | 34.4% |
| Probability of Chl >15 ug/L | 96.0% | | 1.5% | 97.8% | 73.6% | 11.3% |
| Probability of Chl >20 ug/L | 87.9% | | 0.3% | 92.6% | 52.3% | 3.7% |
| Probability of Chl >30 ug/L | 64.1% | | 0.0% | 73.8% | 22.5% | 0.5% |
| Probability of Chl >40 ug/L | 41.5% | | 0.0% | 52.5% | 9.2% | 0.1% |

### Changes in Land Use

Another common scenario to be tested involves changes in land use. How much worse might conditions become if all buildable land became developed? For the example system, with current zoning and protection of some undeveloped areas, a substantial fraction of currently forested areas could still become low density residential housing. Adjusting the land uses in the corresponding input table to reflect a conversion of forest to low density urban development, as shown below, and adding 28 septic systems to that portion of the loading analysis (not shown here) an increase in TP, TN and Chl is derived, and a decrease in SDT are observed (see summary table above). TP rises to 83 ug/L and TN to 965 ug/L, but the change in Chl and SDT are not large, as the lake would already be hypereutrophic.

**BASIN AREAS**

| LAND USE | BASIN 1 E. Direct AREA (HA) | BASIN 2 W. Direct AREA (HA) | BASIN 3 Upper T1 AREA (HA) | BASIN 4 Lower T1 AREA (HA) | BASIN 5 W. Upper T2 AREA (HA) | BASIN 6 E. Upper T2 AREA (HA) | BASIN 7 Lower T2 AREA (HA) | BASIN 8 AREA (HA) | BASIN 9 AREA (HA) | BASIN 10 AREA (HA) | TOTAL AREA (HA) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Urban 1 (Residential) | 16.0 | 18.5 | 23.4 | 87.4 | 6.7 | 12.5 | 38.6 | | | | 203.1 |
| Orginal Urban 1 | 12.0 | 8.5 | 8.4 | 47.4 | 6.7 | 4.5 | 18.1 | | | | |
| Urban 2 (Roads) | 3.7 | 5.5 | 0.0 | 5.9 | 0.8 | 0.6 | 2.3 | | | | 18.8 |
| Urban 3 (Mixed Urban/Commercial) | 3.6 | 5.8 | 0.0 | 5.9 | 0.8 | 0.6 | 2.3 | | | | 19.0 |
| Urban 4 (Industrial) | 0.0 | 0.0 | 0.0 | 23.5 | 0.0 | 0.0 | 0.0 | | | | 23.5 |
| Urban 5 (Parks, Recreation Fields, Institutional) | 0.0 | 3.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | | | | 3.2 |
| Agric 1 (Cover Crop) | 0.0 | 0.0 | 0.0 | 0.8 | 12.3 | 0.0 | 0.0 | | | | 13.1 |
| Agric 2 (Row Crop) | 0.0 | 0.0 | 0.0 | 0.0 | 16.2 | 0.0 | 0.0 | | | | 16.2 |
| Agric 3 (Grazing) | 0.0 | 0.0 | 0.0 | 0.0 | 4.0 | 0.0 | 0.0 | | | | 4.0 |
| Agric 4 (Feedlot) | 0.0 | 0.0 | 0.0 | 0.0 | 0.5 | 0.0 | 0.0 | | | | 0.5 |
| Forest 1 (Upland) | 3.7 | 7.5 | 35.3 | 50.3 | 9.2 | 24.0 | 13.0 | | | | 143.0 |
| Original Forest 1 | 7.7 | 17.5 | 50.3 | 90.3 | 9.2 | 32.0 | 33.6 | | | | 240.6 |
| Forest 2 (Wetland) | 0.0 | 0.2 | 0.0 | 14.5 | 0.0 | 0.0 | 1.9 | | | | 16.6 |
| Open 1 (Wetland/Lake) | 2.5 | 0.6 | 2.0 | 0.1 | 0.0 | 0.1 | 14.2 | | | | 19.5 |
| Open 2 (Meadow) | 2.0 | 1.3 | 0.0 | 10.2 | 0.1 | 0.0 | 0.2 | | | | 13.8 |
| Open 3 (Excavation) | 0.1 | 0.1 | 0.0 | 2.3 | 0.0 | 0.0 | 0.0 | | | | 2.5 |
| Other 1 | | | | | | | | | | | 0.0 |
| Other 2 | | | | | | | | | | | 0.0 |
| Other 3 | | | | | | | | | | | 0.0 |
| | | | | | | | | | | | |
| TOTAL | 31.6 | 42.7 | 60.7 | 200.9 | 50.6 | 37.8 | 72.5 | | | | 496.8 |

### Changes in Wastewater Management

Managing wastewater is often a need in lake communities. In LLRM, wastewater treatment facilities (WWTF) are represented as point sources, with flow and concentration provided. On-site wastewater disposal (septic) systems are part of the baseflow of drainage areas with tributaries, and can be represented that way for direct drainage areas as well, but the option exists to account separately for septic systems in the direct drainage area. Changes to point sources or septic systems can be made in LLRM to simulate possible management actions.

In the example system, there is one small WWTF that discharges into Lower Tributary #1 and 250 residential units that contribute to septic system inputs in the two defined direct drainage areas (see Figure 1). If the units now served by septic systems were tied into the WWTF via a pumping station, the flow through the WWTF would increase from 45,000 cu.m/yr under current conditions to 71,953 cu.m/yr, the amount of wastewater calculated to be generated by those 250 residential units. If WWTF effluent limits for TP and TN were established at 0.1 and 3.0 mg/L, respectively, the concentration in the discharge would be reduced from 3.0 and 12.0 mg/L (current values from monitoring) to the new effluent limits. The result would be a higher flow from the WWTF with lower TP and TN levels, and an elimination of septic system inputs in the model, both simple changes to make, as shown in the table below.

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **NON-AREAL SOURCES** | | | | | | | | | | | | |
| | Number of Source Units | Volume (cu.m/yr) | P Load/Unit (kg/unit/yr) | N Load/Unit (kg/unit/yr) | P Conc. (ppm) | N Conc. (ppm) | P Load (kg/yr) | N Load (kg/yr) | | | | |
| Waterfowl | 50 | | 0.20 | 0.95 | | | 10 | 47.5 | | | | |
| Point Sources | | | | | | | | | | | | |
| PS-1 | | 71953 | | | 0.10 | 3.00 | 7.2 | 215.9 | | | | |
| PS-2 | | 0 | | | 3.00 | 12.00 | 0 | 0 | | | | |
| PS-3 | | 0 | | | 3.00 | 12.00 | 0 | 0 | | | | |
| Basin in which Point Source occurs (0=NO 1=YES) | | | | | | | | | | | | |
| | BASIN 1 | BASIN 2 | BASIN 3 | BASIN 4 | BASIN 5 | BASIN 6 | BASIN 7 | BASIN 8 | BASIN 9 | BASIN 10 | | |
| PS-1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | | |
| PS-2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | |
| PS-3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | |
| | | | | | | | | | | | | |
| **DIRECT SEPTIC SYSTEM LOAD** | | | | | | | | | | | | |
| Septic System Grouping (by occupancy or location) | Days of Occupancy/Year | Distance from Lake (ft) | Number of Dwellings | Number of People per Dwelling | Water per Person per Day (cu.m) | P Conc. (ppm) | N Conc. (ppm) | P Attenuation Factor | N Attenuation Factor | Water Load (cu.m/yr) | P Load (kg/yr) | N Load (kg/yr) |
| Group 1 Septic Systems | 365 | <100 | 0 | 2.5 | 0.25 | 8 | 20 | 0.2 | 0.9 | 0 | 0.0 | 0.0 |
| Group 2 Septic Systems | 365 | 100 - 300 | 0 | 2.5 | 0.25 | 8 | 20 | 0.1 | 0.8 | 0 | 0.0 | 0.0 |
| Group 3 Septic Systems | 90 | <100 | 0 | 2.5 | 0.25 | 8 | 20 | 0.2 | 0.9 | 0 | 0.0 | 0.0 |
| Group 4 Septic Systems | 90 | 100 - 300 | 0 | 2.5 | 0.25 | 8 | 20 | 0.1 | 0.8 | 0 | 0.0 | 0.0 |
| | | | | | | | | | | | | |
| Total Septic System Loading | | | | | | | | | | 0 | 0.0 | 0.0 |

The result, shown in the summary table for scenario testing above, is an in-lake TP concentration of 49 ug/L and a new TN level of 745 ug/L. These are both substantial reductions from the current levels, but continued elevated Chl (mean = 23.3 ug/L, peak = 76.1 ug/L) and a high probability of algal blooms is expected. Water clarity improves slightly (from 0.8 to 1.2 m on average), but at the cost of the sewerage and treatment, this is unlikely to produce a success story.

**Best Management Practices**

The application of BMPs is generally regarded as the backbone of non-point source pollution management in watershed programs. Considerable effort has been devoted to assessing the percent removal for various pollutants that can be attained and sustained by various BMPs. BMPs tend to fall into one of two categories: source controls and pollutant trapping. Source controls limit the generation of TP and TN and include actions like bans on lawn fertilizers containing TP or requirements for post-development infiltration to equal pre-development conditions, and would be most likely addressed in LLRM by a change in export coefficient. Pollutant trapping limits the delivery of generated loads to the lake and includes such methods as detention, infiltration, and buffer strips, and is most often addressed in LLRM by changes in attenuation values.

There are limits on what individual BMPs can accomplish. While some site specific knowledge and sizing considerations help modify general guidelines, the following table provides a sense for the level of removal achievable with common BMPs.

**Range and Median for Expected Removal (%) for Key Pollutants by Selected Management Methods, Compiled from Literature Sources for Actual Projects and Best Professional Judgment Upon Data Review.**

| | TSS | Total P | Soluble P | Total N | Soluble N | Metals |
|---|---|---|---|---|---|---|
| Street sweeping | 5-20 | 5-20 | <5 | 5-20 | <5 | 5-20 |
| Catch basin cleaning | 5-10 | <10 | <1 | <10 | <1 | 5-10 |
| Buffer strips | 40-95 | 20-90 | 10-80 | 20-60 | 0-20 | 20-60 |
| | (50) | (30) | (20) | (30) | (5) | (30) |
| Conventional catch basins | 1-20 | 0-10 | 0-1 | 0-10 | 0-1 | 1-20 |
| (Some sump capacity) | (5) | (2) | (0) | (2) | (0) | (5) |
| Modified catch basins (deep | 25 | 0-20 | 0-1 | 0-20 | 0-1 | 20 |
| sumps and hoods) | (25) | (5) | (0) | (5) | (0) | (20) |
| Advanced catch basins | 25-90 | 0-19 | 0-21 | 0-20 | 0-6 | 10-30 |
| (sediment/floatables traps) | (50) | (10) | (0) | (10) | (0) | (20) |
| Porous Pavement | 40-80 | 28-85 | 0-25 | 40-95 | -10-5 | 40-90 |
| | (60) | (52) | (10) | (62) | (0) | (60) |
| Vegetated swale | 60-90 | 0-63 | 5-71 | 0-40 | -25-31 | 50-90 |
| | (70) | (30) | (35) | (25) | (0) | (70) |
| Infiltration trench/chamber | 75-90 | 40-70 | 20-60 | 40-80 | 0-40 | 50-90 |
| | (80) | (60) | (50) | (60) | (10) | (80) |
| Infiltration basin | 75-80 | 40-100 | 25-100 | 35-80 | 0-82 | 50-90 |
| | (80) | (65) | (55) | (51) | (15) | (80) |
| Sand filtration system | 80-85 | 38-85 | 35-90 | 22-73 | -20-45 | 50-70 |
| | (80) | (62) | (60) | (52) | (13) | (60) |
| Organic filtration system | 80-90 | 21-95 | -17-40 | 19-55 | -87-0 | 60-90 |
| | (80) | (58) | (22) | (35) | (-50) | (70) |
| Dry detention basin | 14-87 | 23-99 | 5-76 | 29-65 | -20-10 | 0-66 |
| | (70) | (65) | (40) | (46) | (0) | (36) |
| Wet detention basin | 32-99 | 13-56 | -20-5 | 10-60 | 0-52 | 13-96 |
| | (70) | (27) | (-5) | (31) | (10) | (63) |
| Constructed wetland | 14-98 | 12-91 | 8-90 | 6-85 | 0-97 | 0-82 |
| | (70) | (49) | (63) | (34) | (43) | (54) |
| Pond/Wetland Combination | 20-96 | 0-97 | 0-65 | 23-60 | 1-95 | 6-90 |
| | (76) | (55) | (30) | (39) | (49) | (58) |
| Chemical treatment | 30-90 | 24-92 | 1-80 | 0-83 | 9-70 | 30-90 |
| | (70) | (63) | (42) | (38) | (34) | (65) |

While BMPs in series can improve removal, the result is rarely multiplicative; that is, application of two BMPs expected to remove 50% of TP are unlikely to result in 0.5 X 0.5 = 0.25 of the load remaining (75% removal) unless each BMP operates on a different fraction of TP (particulates vs. soluble, for example). This is where judgment and experience become critical to the modeling process. In general, BMPs rarely remove more than 2/3 of the load of P or N, and on average can be expected to remove around 50% of the P and 40% of the N unless very carefully designed, built and maintained. The luxury of space is not often affordable, forcing creativity or greater expense to achieve higher removal rates.

In the example system, setting attenuation for all basins to 0.5 for P and 0.6 for N is viewed as a practical level of BMP application for a first cut at what BMPs might be able to do for the lake. Careful consideration of which BMPs will be applied where in which basins is in order in the final analysis, but to set a reasonable approximation of what can be achieved, these are supportable attenuation values. Note that values are not set at 0.5 or 0.6 of the value in place in the calibrated model, but rather a low end of 0.5 or

0.6. If, as with Basin 7 (Lower Tributary #2) in the example system, the attenuation values for P and N under current conditions are 0.70 and 0.75, the practical BMP values of 0.5 and 0.6, respectively, represent less of a decline through BMPs than for the direct drainage areas, which have current condition attenuation values of 0.9 for P and 0.95 for N.

In addition to setting P attenuation at 0.5 for P in all basins and 0.6 for N in all basins in the example system, the WWTF has been routed to a regional WWTF out of the watershed, and the all areas within 300 ft of the lake have been sewered, with that waste also going to the regional WWTF. Consequently, the WWTF and direct drainage septic system inputs have been eliminated. Finally, internal loading has been reduced to 0.5 mg P/m/day and 2.0 mg N/m$^2$/day, achievable with nutrient inactivation and lowered inputs over time.

The results, as indicated in the summary table for scenario testing above, include an in-lake P concentration of 24 ug/L and an N level of 540 ug/L. The predicted mean Chl is 9.3 ug/L, with a peak of 31.6 ug/L. SDT would be expected to average 2.0 m and have a maximum of 4.0 m. While much improved over current conditions, these are marginal values for supporting the range of lake uses, particularly contact recreation and potable water supply. As a first cut assessment of what BMPs might do for the system, it suggests that more extreme measures will be needed, or that in-lake maintenance should be planned as well, since algal blooms would still be expected. Further scenario testing with the model, combined with cost estimation for potential BMPs, may shed light on the cost effectiveness of rehabilitating the example lake.

# Appendix C:

# Land Use Categories, Export Coefficients and Additional Calculations

**Table C-1. Runoff and baseflow fraction ranges.**

| | Low | Med | High |
|---|---|---|---|
| Baseflow fraction | 0.10 | 0.40 | 0.95 |
| Runoff fraction | 0.01 | 0.20 | 0.40 |

**Table C-2. Runoff and baseflow factions used in the model for Tom Pond.**

| Landuse Category | Runoff Fraction | Baseflow Fraction |
|---|---|---|
| Urban 1 (Low Density Non-Shoreline Residential) | 0.35 | 0.30 |
| Urban 2 (Shoreline Residential/Commercial) | 0.45 | 0.20 |
| Urban 3 (Roads) | 0.60 | 0.05 |
| Urban 4 (Industrial) | 0.60 | 0.05 |
| Urban 5 (Parks, Recreation Fields, Institutional) | 0.20 | 0.40 |
| Agric 1 (Cover Crop) | 0.15 | 0.30 |
| Agric 2 (Row Crop) | 0.25 | 0.35 |
| Agric 3 (Grazing) | 0.25 | 0.35 |
| Agric 4 (Hayland-Non Manure) | 0.25 | 0.35 |
| Forest 1 (Deciduous) | 0.30 | 0.40 |
| Forest 2 (Non-Deciduous) | 0.30 | 0.40 |
| Forest 3 (Mixed Forest) | 0.30 | 0.40 |
| Forest 4 (Wetland) | 0.05 | 0.40 |
| Open 1 (Wetland / Pond) | 0.05 | 0.40 |
| Open 2 (Meadow) | 0.05 | 0.40 |
| Open 3 (Cleared/Disturbed Land) | 0.20 | 0.40 |

**Table C-3. Land use categories from used in Tom Pond ENSR-LRM.**

| ENSR-LRM LAND USE | Land Cover Code[1] | Land Cover Description | NWI code[2] | Windshield Survey |
|---|---|---|---|---|
| Urban 1 (Low Density Non-Shoreline Residential) | 110 | Residential/Commericial/Industrial | non wetland area | |
| Urban 2 (Shoreline Residential/Commercial) | 110 | Residential/Commericial/Industrial | non wetland area | |
| Urban 3 (Roads) | 140 | Transportation/Roads | | |
| Urban 4 (Industrial) | 110 | Residential/Commericial/Industrial | | |
| Urban 5 (Parks, Recreation Fields, Institutional) | 790 | | | X |
| Agric 1 (Cover Crop) | 211 | | | X |
| Agric 2 (Row Crop) | 211 | Row Crops | | X |
| Agric 3 (Grazing) | 212 | Hay/Pasture | | X |
| Agric 4 (Hayland-no manure) | 212 | Hay/Pasture | | X |
| Agric 5 (Orchard) | 221 | Fruit Orchard | | |
| Forest 1 (Deciduous) | 412 | Beech/oak | | |
| | 414 | Paper birch/aspen | | |
| | 419 | Other hardwoods | | |
| Forest 2 (Non-Deciduous) | 421 | White/red pine | | |
| | 422 | Spruce/fir | | |
| | 423 | Hemlock | | |
| | 424 | Pitch pine | | |
| Forest 3 (Mixed) | 430 | Mixed forest | | |
| Forest 4 (Wetland) | 610 | Forested wetlands | PF___ | |
| Open 1 (Wetland / Lake) | 500 | Water | | |
| | 620 | Open Water/Wetland | PSS_, L1_, PEM__ | |
| Open 2 (Meadow) | 212 | Hay/Pasture | | X |
| Open 3 (Cleared/Disturbed Land) | 790 | Cleared/other open | | X |
| | 710 | Disturbed | | X |

1 Land cover data created by GRANIT using Lansat 5 and 7 imagery and other available raster and vector data.

2 National Wetlands Inventory (NWI) data is used to improve the accuracy of wetland areas that are either not delineated in the land use and land cover data or poorly represented by raster cells.

Priority ranking is given to the Land Use data set for all non-wetland areas, NWI data for wetland areas, and Land cover for forest type areas.

**Table C-4. Land use export coefficients (kg/ha/yr) used in Tom Pond TMDL.***

| ENSR-LRM Land Use | Runoff P export coefficient range | Runoff P export coefficient used | Source | Baseflow P export coefficient range | Baseflow P export coefficient used | Source |
|---|---|---|---|---|---|---|
| Urban 1 (Low Density Non-Shoreline Residential) | 0.11-8.42 | 0.35* | Reckhow et al. 1980, Schloss et al. 2000-Table 5 | 0.001-0.05 | 0.01 | ENSR Unpublished Data; Mitchell et al. 1989 |
| Urban 2 (Shoreline Residential/Commercial) | 0.11-8.42 | 0.9* | Reckhow et al. 1980 | 0.001-0.05 | 0.01 | " |
| Urban 3 (Roads) | 0.60-10 | 1.5* | Dudley et al. 1997 | 0.001-0.05 | 0.01 | " |
| Urban 4 (Industry) | 0.11-8.42 | 1.5* | Reckhow et al. 1980 | 0.001-0.05 | 0.01 | " |
| Urban 5 (Park/Institutional/Recreation/Cemetery) | 0.19-6.23 | 0.8 | Reckhow et al. 1980 | 0.001-0.05 | 0.01 | " |
| Agric 1 (Cover Crop) | 0.10-2.90 | 0.8 | Reckhow et al. 1980 | 0.001-0.05 | 0.01 | " |
| Agric 2 (Row Crop) | 0.26-18.26 | 2.2 | Reckhow et al. 1980 | 0.001-0.05 | 0.01 | " |
| Agric 3 (Grazing) | 0.14-4.90 | 0.8 | Reckhow et al. 1980 | 0.001-0.05 | 0.01 | " |
| Agric 4 (Hayland-No Manure) | 0.35 | 0.35* | Dennis and Sage 1981 | 0.001-0.05 | 0.01 | " |
| Forest 1 (Deciduous) | 0.034-0.973 | 0.15 | Schloss et al. 2000- Table 4 | 0.001-0.010 | 0.004 | " |
| Forest 2 (Non-Deciduous) | 0.01-0.138 | 0.093 | Schloss et al. 2000- Table 4 | 0.001-0.010 | 0.004 | " |
| Forest 3 (Mixed) | 0.01-0.138 | 0.093 | Schloss et al. 2000- Table 4 | 0.001-0.010 | 0.004 | " |
| Forest 4 (Wetland) | 0.003-0.439 | 0.082 | Schloss et al. 2000-Table 4 | 0.001-0.010 | 0.004 | " |
| Open 1 (Wetland / Pond) | 0.009-0.25 | 0.065* | Schloss et al. 2000-Table 5 | 0.001-0.010 | 0.004 | " |
| Open 2 (Meadow) | 0.02-0.83 | 0.8 | Reckhow et al. 1980 | 0.001-0.010 | 0.01 | " |
| Open 3 (Bare Open) | 0.25-1.75 | 0.8 | Reckhow et al. 1980 | 0.001-0.010 | 0.01 | " |

*Value is not a median

**Table C-5. Internal loading calculations in Tom Pond model.**

Weakly stratified, Internal Load
not calculated

**Table C-6. Septic system calculations in Tom Pond model.**

| Category | # of Dwellings in 125 ft Buffer | People/ Dwelling | TP Atten Factor | Mean TP Conc (mg/L) | P Load (kg/person/yr) | P Load (kg/yr) | Water (gal/day) | # of Days | Water Load ($m^3$/yr) |
|---|---|---|---|---|---|---|---|---|---|
| Year Round Residential | 27 | 2.5 | 0.1 | 8 | 0.72 | 4.8 | 65 | 365 | 6062.1 |
| Seasonal Residential | 18 | 2.5 | 0.1 | 8 | 0.18 | 0.8 | 65 | 90 | 996.5 |
| Total Septic System Loading | | | | | | 5.6 | | | 7058.6 |

**Table C-7. Waterfowl loading calculations in Tom Pond model.**

| Bird Type | # of Birds | P Load (kg/bird/day) | Non-Ice Days (days) | P Load (kg/yr) | Coefficient Source | Bird Count Source |
|---|---|---|---|---|---|---|
| Canada Geese | 2 | 0.001526 | 275 | 0.8 | Scherer et al., 1995 | Hamilton, 2008 |

**Table C-8. Predicted water quality parameters for Tom Pond in the predevelopment scenario.**

## Tom Pond- Predevelopment Scenario

| Empirical Equation | Equation | Predicted TP (*u* g/L) |
|---|---|---|
| Mass Balance | TP=L/(Z(F))*1000 | 8 |
| Kirchner-Dillon 1975 | TP=L(1-Rp)/(Z(F))*1000 | 5 |
| Vollenweider 1975 | TP=L/(Z(S+F))*1000 | 7 |
| Larsen-Mercier 1976 | TP=L(1-Rlm)/(Z(F))*1000 | 6 |
| Jones-Bachmann 1976 | TP=0.84(L)/(Z(0.65+F))*1000 | 6 |
| Reckhow General 1977 | TP=L/(11.6+1.2(Z(F)))*1000 | 4 |
| **Average of Above 5 Model Values** | | ***6*** |

| Variable | Description | Units | Equation |
|---|---|---|---|
| L | Phosphorus Load to Pond | g P/m2/yr | |
| Z | Mean Depth | m | Volume/area |
| F | Flushing Rate | flushings/yr | Inflow/volume |
| S | Suspended Fraction | no units | Effluent TP/Influent TP |
| Qs | Areal Water Load | m/yr | Z(F) |
| Vs | Settling Velocity | m | Z(S) |
| Rp | Retention Coefficient (settling rate) | no units | ((Vs+13.2)/2)/(((Vs+13.2)/2)+Qs) |
| Rlm | Retention Coefficient (flushing rate) | no units | 1/(1+F^0.5) |

| Empirical Equation | Equation | Predicted Value |
|---|---|---|
| ***Mean Chlorophyll*** | | ***u* g/L** |
| Carlson 1977 | Chl=0.087*(Pred TP)^1.45 | 1.0 |
| Dillon and Rigler 1974 | Chl=10^(1.449*LOG(Pred TP)-1.136) | 0.9 |
| Jones and Bachmann 1976 | Chl=10^(1.46*LOG(Pred TP)-1.09) | 1.0 |
| Oglesby and Schaffner 1978 | Chl=0.574*(Pred TP)-2.9 | 0.3 |
| Modified Vollenweider 1982 | Chl=2*0.28*(Pred TP)^0.96 | 2.9 |
| **Average of Model Values** | | **1.2** |
| ***Peak Chlorophyll*** | | ***u* g/L** |
| Modified Vollenweider (TP) 1982 | Chl=2*0.64*(Pred TP)^1.05 | 7.7 |
| Vollenweider (CHL) 1982 | Chl=2.6*(AVERAGE(Pred Chl))^1.06 | 3.2 |
| Modified Jones, Rast and Lee 1979 | Chl=2*1.7*(AVERAGE(Pred Chl))+0.2 | 4.3 |
| **Average of Model Values** | | **5.0** |
| ***Bloom Probability*** | | ***% of Summer*** |
| Probability of Chl >15 *u* g/L | See Walker 1984 & 2000 | 0.0% |
| ***Secchi Transparency*** | | ***m*** |
| **Mean:** Oglesby and Schaffner 1978 | Chl=10^(1.36-0.764*LOG(Pred TP)) | 6.2 |
| **Max:** Modified Vollenweider 1982 | Chl=9.77*Pred TP^-0.28 | 6.1 |

| Variable | Description | Units |
|---|---|---|
| "Pred TP" | The average TP calculated from the 5 predictive equation models | *u* g/L |
| "Pred Chl" | The average of the 3 predictive equations calculating mean chlorophyll | *u* g/L |

**Table C-9. Predicted water quality parameters for Tom Pond in the scenario without septic system loading.**

## Tom Pond- Scenario without Septic System Loading

| Empirical Equation | Equation | Predicted TP (*u* g/L) |
|---|---|---|
| Mass Balance | TP=L/(Z(F))*1000 | 15 |
| Kirchner-Dillon 1975 | TP=L(1-Rp)/(Z(F))*1000 | 10 |
| Vollenweider 1975 | TP=L/(Z(S+F))*1000 | 13 |
| Larsen-Mercier 1976 | TP=L(1-Rlm)/(Z(F))*1000 | 11 |
| Jones-Bachmann 1976 | TP=0.84(L)/(Z(0.65+F))*1000 | 11 |
| Reckhow General 1977 | TP=L/(11.6+1.2(Z(F)))*1000 | 7 |
| **Average of Above 5 Model Values** | | ***10*** |

| Variable | Description | Units | Equation |
|---|---|---|---|
| L | Phosphorus Load to Pond | g P/m2/yr | |
| Z | Mean Depth | m | Volume/area |
| F | Flushing Rate | flushings/yr | Inflow/volume |
| S | Suspended Fraction | no units | Effluent TP/Influent TP |
| Qs | Areal Water Load | m/yr | Z(F) |
| Vs | Settling Velocity | m | Z(S) |
| Rp | Retention Coefficient (settling rate) | no units | ((Vs+13.2)/2)/(((Vs+13.2)/2)+Qs) |
| Rlm | Retention Coefficient (flushing rate) | no units | 1/(1+F^0.5) |

| Empirical Equation | Equation | Predicted Value |
|---|---|---|
| ***Mean Chlorophyll*** | | ***u* g/L** |
| Carlson 1977 | Chl=0.087*(Pred TP)^1.45 | 2.6 |
| Dillon and Rigler 1974 | Chl=10^(1.449*LOG(Pred TP)-1.136) | 2.2 |
| Jones and Bachmann 1976 | Chl=10^(1.46*LOG(Pred TP)-1.09) | 2.5 |
| Oglesby and Schaffner 1978 | Chl=0.574*(Pred TP)-2.9 | 3.1 |
| Modified Vollenweider 1982 | Chl=2*0.28*(Pred TP)^0.96 | 5.3 |
| **Average of Model Values** | | **3.1** |
| ***Peak Chlorophyll*** | | ***u* g/L** |
| Modified Vollenweider (TP) 1982 | Chl=2*0.64*(Pred TP)^1.05 | 15.0 |
| Vollenweider (CHL) 1982 | Chl=2.6*(AVERAGE(Pred Chl))^1.06 | 8.7 |
| Modified Jones, Rast and Lee 1979 | Chl=2*1.7*(AVERAGE(Pred Chl))+0.2 | 10.9 |
| **Average of Model Values** | | **11.5** |
| ***Bloom Probability*** | | ***% of Summer*** |
| Probability of Chl >15 *u* g/L | See Walker 1984 & 2000 | 0.0% |
| ***Secchi Transparency*** | | ***m*** |
| **Mean:** Oglesby and Schaffner 1978 | Chl=10^(1.36-0.764*LOG(Pred TP)) | 3.8 |
| **Max:** Modified Vollenweider 1982 | Chl=9.77*Pred TP^-0.28 | 5.1 |

| Variable | Description | Units |
|---|---|---|
| "Pred TP" | The average TP calculated from the 5 predictive equation models | *u* g/L |
| "Pred Chl" | The average of the 3 predictive equations calculating mean chlorophyll | *u* g/L |

**Table C-10. Predicted water quality parameters for Tom Pond in the scenario with periodic Warner River backflow.**

## Tom Pond- Current Conditions with Periodic Warner River Backflow

| Empirical Equation | Equation | Predicted TP (*u* g/L) |
|---|---|---|
| Mass Balance | TP=L/(Z(F))*1000 | 34 |
| Kirchner-Dillon 1975 | TP=L(1-Rp)/(Z(F))*1000 | 23 |
| Vollenweider 1975 | TP=L/(Z(S+F))*1000 | 30 |
| Larsen-Mercier 1976 | TP=L(1-Rlm)/(Z(F))*1000 | 24 |
| Jones-Bachmann 1976 | TP=0.84(L)/(Z(0.65+F))*1000 | 26 |
| Reckhow General 1977 | TP=L/(11.6+1.2(Z(F)))*1000 | 17 |
| **Average of Above 5 Model Values** | | ***24*** |
| ***Observed Summer Epilimnion Mean*** | | ***10*** |
| ***Observed Summer Epilimnion Median*** | | ***10*** |

| Variable | Description | Units | Equation |
|---|---|---|---|
| L | Phosphorus Load to Pond | g P/m2/yr | |
| Z | Mean Depth | m | Volume/area |
| F | Flushing Rate | flushings/yr | Inflow/volume |
| S | Suspended Fraction | no units | Effluent TP/Influent TP |
| Qs | Areal Water Load | m/yr | Z(F) |
| Vs | Settling Velocity | m | Z(S) |
| Rp | Retention Coefficient (settling rate) | no units | ((Vs+13.2)/2)/(((Vs+13.2)/2)+Qs) |
| Rlm | Retention Coefficient (flushing rate) | no units | 1/(1+F^0.5) |

| Empirical Equation | Equation | Predicted Value |
|---|---|---|
| ***Mean Chlorophyll*** | | ***u* g/L** |
| Carlson 1977 | Chl=0.087*(Pred TP)^1.45 | 8.8 |
| Dillon and Rigler 1974 | Chl=10^(1.449*LOG(Pred TP)-1.136) | 7.4 |
| Jones and Bachmann 1976 | Chl=10^(1.46*LOG(Pred TP)-1.09) | 8.5 |
| Oglesby and Schaffner 1978 | Chl=0.574*(Pred TP)-2.9 | 10.9 |
| Modified Vollenweider 1982 | Chl=2*0.28*(Pred TP)^0.96 | 11.9 |
| **Average of Model Values** | | **9.5** |
| ***Observed Summer Mean*** | | ***9.5*** |
| ***Peak Chlorophyll*** | | ***u* g/L** |
| Modified Vollenweider (TP) 1982 | Chl=2*0.64*(Pred TP)^1.05 | 36.2 |
| Vollenweider (CHL) 1982 | Chl=2.6*(AVERAGE(Pred Chl))^1.06 | 28.2 |
| Modified Jones, Rast and Lee 1979 | Chl=2*1.7*(AVERAGE(Pred Chl))+0.2 | 32.5 |
| **Average of Model Values** | | **32.3** |
| ***Observed Summer Maximum**** | | ***36.7*** |
| ***Bloom Probability*** | | ***% of Summer*** |
| Probability of Chl >15 *u* g/L | See Walker 1984 & 2000 | 12.2% |
| ***Secchi Transparency*** | | ***m*** |
| **Mean:** Oglesby and Schaffner 1978 | Chl=10^(1.36-0.764*LOG(Pred TP)) | 2.0 |
| **Max:** Modified Vollenweider 1982 | Chl=9.77*Pred TP^-0.28 | 4.0 |
| ***Observed Summer Mean*** | | ***2.85*** |
| ***Observed Summer Maximum*** | | ***3.75*** |

| Variable | Description | Units |
|---|---|---|
| "Pred TP" | The average TP calculated from the 5 predictive equation models | *u* g/L |
| "Pred Chl" | The average of the 3 predictive equations calculating mean chlorophyll | *u* g/L |

*The observed summer maximum is based on n=22 and is not necessarily the peak chlorophyll

**Table C-11. Predicted water quality parameters for Tom Pond in the scenario at the target in-lake concentration of 12 *u* g/L.**

## Tom Pond- Target Scenario- In-lake Concentration of 12 *u* g/L

| Empirical Equation | Equation | Predicted TP (*u* g/L) |
|---|---|---|
| Mass Balance | TP=L/(Z(F))*1000 | 17 |
| Kirchner-Dillon 1975 | TP=L(1-Rp)/(Z(F))*1000 | 11 |
| Vollenweider 1975 | TP=L/(Z(S+F))*1000 | 15 |
| Larsen-Mercier 1976 | TP=L(1-Rlm)/(Z(F))*1000 | 12 |
| Jones-Bachmann 1976 | TP=0.84(L)/(Z(0.65+F))*1000 | 13 |
| Reckhow General 1977 | TP=L/(11.6+1.2(Z(F)))*1000 | 9 |
| **Average of Above 5 Model Values** | | ***12*** |

| Variable | Description | Units | Equation |
|---|---|---|---|
| L | Phosphorus Load to Pond | g P/m2/yr | |
| Z | Mean Depth | m | Volume/area |
| F | Flushing Rate | flushings/yr | Inflow/volume |
| S | Suspended Fraction | no units | Effluent TP/Influent TP |
| Qs | Areal Water Load | m/yr | Z(F) |
| Vs | Settling Velocity | m | Z(S) |
| Rp | Retention Coefficient (settling rate) | no units | ((Vs+13.2)/2)/(((Vs+13.2)/2)+Qs) |
| Rlm | Retention Coefficient (flushing rate) | no units | 1/(1+F^0.5) |

| Empirical Equation | Equation | Predicted Value |
|---|---|---|
| ***Mean Chlorophyll*** | | ***u* g/L** |
| Carlson 1977 | Chl=0.087*(Pred TP)^1.45 | 3.2 |
| Dillon and Rigler 1974 | Chl=10^(1.449*LOG(Pred TP)-1.136) | 2.7 |
| Jones and Bachmann 1976 | Chl=10^(1.46*LOG(Pred TP)-1.09) | 3.1 |
| Oglesby and Schaffner 1978 | Chl=0.574*(Pred TP)-2.9 | 4.0 |
| Modified Vollenweider 1982 | Chl=2*0.28*(Pred TP)^0.96 | 6.1 |
| **Average of Model Values** | | **3.8** |
| ***Peak Chlorophyll*** | | ***u* g/L** |
| Modified Vollenweider (TP) 1982 | Chl=2*0.64*(Pred TP)^1.05 | 17.4 |
| Vollenweider (CHL) 1982 | Chl=2.6*(AVERAGE(Pred Chl))^1.06 | 10.7 |
| Modified Jones, Rast and Lee 1979 | Chl=2*1.7*(AVERAGE(Pred Chl))+0.2 | 13.2 |
| **Average of Model Values** | | **13.8** |
| ***Bloom Probability*** | | ***% of Summer*** |
| Probability of Chl >15 *u* g/L | See Walker 1984 & 2000 | 0.1% |
| ***Secchi Transparency*** | | ***m*** |
| **Mean:** Oglesby and Schaffner 1978 | Chl=10^(1.36-0.764*LOG(Pred TP)) | 3.4 |
| **Max:** Modified Vollenweider 1982 | Chl=9.77*Pred TP^-0.28 | 4.9 |

| Variable | Description | Units |
|---|---|---|
| "Pred TP" | The average TP calculated from the 5 predictive equation models | *u* g/L |
| "Pred Chl" | The average of the 3 predictive equations calculating mean chlorophyll | *u* g/L |